



## AN ABSTRACT OF THE THESIS OF

Natalie R. Macias for the degree of Master of Science in Wood Science  
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Title: Commercialization Potential of Viscoelastic Thermal Compressed (VTC)  
Wood.

Abstract approved: \_\_\_\_\_

Christopher D. Knowles

The increasing demand for forest products and restricted use of natural forests has resulted in a shortage of high-strength wood fiber. The area covered by plantation forests is steadily rising, but the fiber produced by these forests is often unsuitable for high-strength applications. One attempt to combat this problem is the Viscoelastic Thermal Compression (VTC) process, which can dramatically increase the strength and stiffness of any wood species.

In order to advance VTC wood from the concept evaluation stage to the development stage, concept testing interviews were conducted with individuals in the forest products industry and with design professionals (i.e. architects, engineers, contractors, etc.). Valuable opinions, ideas, and insights were gathered from interviewees concerning potential applications for VTC wood, as well as advantages and barriers to its commercialization.

Overall, forest products interviewees thought the most viable uses for VTC wood were LVL, plywood, concrete forms, transportation components, and flooring. The most frequently mentioned advantages to commercialization included increased mechanical properties and the utilization of a low-value wood species; barriers to commercialization were cost and the forest products industry's resistance to change. Forest products interviewees thought VTC wood would be successful as long as it was not markedly more expensive than similar products.

Design professionals thought the properties of VTC wood are best suited for use in glulam beams, flooring, cabinetry, and LVL. The most commonly mentioned advantages to commercialization included increased mechanical properties, the ability to achieve greater spans, and the color darkening that occurs during production; barriers to commercialization included cost, energy use during production, and unfamiliarity. Overall, interviewees seemed to think VTC wood could be successfully commercialized if it is cost-competitive, energy-efficient, and tested extensively on a large scale.

As a whole, the interviewees believed that VTC wood has the most potential being successfully commercialized as a component of LVL, flooring, and/or glulam beams. These three products were likely mentioned with the highest frequency because radical changes in production would not need to occur in

order to integrate VTC wood. One (or more) of these three products would be a logical starting point for VTC wood to enter the market. LVL and glulam beams have the potential to gain market share from steel, which could be used as a selling point. Flooring, on the other hand, cannot be used structurally, but may garner higher profits than LVL and glulam beams. Unique product ideas that may warrant additional investigation in the future are components for car/truck/train/boat interiors, commercial truck/trailer beds, retrofitting, SIP panels, benches, specialty pallets/crating, furniture, and export products. While interesting, these types of products may not be worth exploring until VTC wood is proven in more conventional products, such as LVL or glulam beams. However, they should not be ignored due to their potential for higher financial returns.

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Commercialization Potential of Viscoelastic Thermal Compressed (VTC) Wood

by  
Natalie R. Macias

A THESIS

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Natalie R. Macias, Author

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## CONTRIBUTION OF AUTHORS

Dr. Chris Knowles was involved in all aspects of the work leading to this thesis. Chapter 3 was a result of collaboration with Dr. Chris Knowles, Dr. Fred Kamke, and Dr. Andreja Kutnar leading to a manuscript submitted to *Forest Products Journal*. Chapter 4 was a result of collaboration with Dr. Chris Knowles and Dr. Keven Malkewitz leading to a manuscript submitted to *TBA*.

# TABLE OF CONTENTS

	<u>Page</u>
CHAPTER 1 - GENERAL INTRODUCTION.....	1
OBJECTIVES .....	3
CHAPTER 2 – THEORETICAL BACKGROUND.....	4
State of the World’s Forests .....	4
Global Demand for Wood Fiber.....	6
Methods of Wood Densification.....	9
Viscoelastic Thermal Compression (VTC) Process .....	10
Advantages of VTC Wood .....	13
Disadvantages of VTC Wood .....	15
Uses for VTC Wood .....	16
Existing Products Review .....	16
Glulam Beams.....	16
Laminated Veneer Lumber.....	19
Concrete Forms .....	20
Flooring .....	22
New Product Development.....	23
New Product Development Process .....	24
Concept Testing .....	29
Role of Marketing in NPD.....	33
New Product Success and Failure .....	34
LITERATURE CITED.....	37
CHAPTER 3 – COMMERCIALIZATION POTENTIAL OF VISCOELASTIC THERMAL COMPRESSED (VTC) WOOD: INSIGHTS FROM THE U.S. FOREST PRODUCTS INDUSTRY .....	40
ABSTRACT.....	41
INTRODUCTION .....	41

## TABLE OF CONTENTS (Continued)

	Page
OBJECTIVES .....	44
THEORETICAL BACKGROUND .....	45
Global Demand for Wood Fiber .....	45
New Product Development.....	47
NPD and Innovation in the Forest Products Industry .....	48
NPD Processes and Market Research .....	49
Concept Testing .....	50
METHODS AND DATA ANALYSIS .....	53
Methodology .....	53
Personal Interviews.....	53
Study Design .....	54
Interview Protocol Development .....	54
Pre-Testing.....	55
Development of Interview Reference Materials .....	56
Data Collection and Analysis.....	56
Snowball Sampling.....	56
Sample Selection .....	57
Data Collection.....	60
Data Analysis .....	60
RESULTS .....	61
Greatest Unmet Customer Needs .....	61
Applications Where Wood is Limiting .....	64
Potential Products to Incorporate VTC Wood .....	66
Advantages to the Commercialization/Use of VTC Wood.....	68
Barriers to the Commercialization/Use of VTC Wood .....	71

## TABLE OF CONTENTS (Continued)

	<u>Page</u>
Deal Breaker to Use VTC Wood .....	73
DISCUSSION .....	75
Lack of Quality and Consistency .....	75
Products to Incorporate VTC Wood .....	77
Advantages to the Commercialization/Use of VTC Wood.....	78
Barriers to the Commercialization/Use of VTC Wood .....	79
Deal Breaker to Use VTC Wood .....	80
CONCLUSIONS .....	81
LIMITATIONS .....	83
LITERATURE CITED.....	84
CHAPTER 4 – COMMERCIALIZATION POTENTIAL OF VISCOELASTIC THERMAL COMPRESSED (VTC) WOOD: INSIGHTS FROM OREGON DESIGN PROFESSIONALS .....	87
ABSTRACT.....	88
INTRODUCTION .....	88
OBJECTIVES .....	91
THEORETICAL BACKGROUND.....	92
New Product Development.....	92
New Product Development Process .....	93
Concept Testing .....	94
New Product Success and Failure .....	98
Role of Design Professionals in NPD.....	100
METHODS AND DATA ANALYSIS .....	101
Methodology .....	101
Personal interviews .....	102
Study design.....	102

## TABLE OF CONTENTS (Continued)

	<u>Page</u>
Interview protocol development .....	102
Pre-testing .....	104
Development of interview reference materials .....	104
Data Collection and Analysis.....	105
Snowball sampling .....	105
Sample selection.....	105
Data collection.....	106
Data analysis.....	107
RESULTS .....	108
Challenges With Material Selection.....	108
Considerations in Material Specification .....	110
Frequency of Wood Products Specification .....	113
Benefits of Wood-Based Materials .....	114
Limitations of Wood .....	116
Products to Incorporate VTC Wood .....	118
Advantages to the Commercialization/Use of VTC Wood.....	122
Barriers to the Commercialization/Use of VTC Wood .....	125
Deal Breaker to Use VTC Wood .....	128
Relationship Among Design Professionals .....	129
DISCUSSION .....	130
Challenges and Considerations of Material Selection.....	130
Benefits and Limitations of Wood.....	132
Products to Incorporate VTC Wood .....	133
Advantages to the Commercialization/Use of VTC Wood.....	134
Barriers to the Commercialization/Use of VTC Wood .....	135

## TABLE OF CONTENTS (Continued)

	<u>Page</u>
CONCLUSIONS .....	137
LIMITATIONS .....	138
LITERATURE CITED.....	139
CHAPTER 5 – GENERAL CONCLUSIONS .....	144
THESIS LITERATURE CITED.....	148
APPENDIX.....	152

## LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. VTC Continuous Process.....	12
2. NPD Process.....	27

## LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Mechanical properties for VTC wood and commonly used species..	12
2. Semi-structured interview protocol for forest products industry.....	55
3. Forest products interviewees by position and location of interview...	59
4. Greatest unmet customer needs.....	62
5. Applications where wood is limiting.....	64
6. Potential products to incorporate VTC wood.....	66
7. Advantages to the commercialization/use of VTC wood.....	69
8. Barriers to the commercialization/use of VTC wood.....	71
9. Deal breaker to use VTC wood.....	74
10. Semi-structured interview protocol for design professionals.....	103
11. Design professional interviewees by profession.....	106
12. Challenges with material selection.....	109
13. Considerations in material selection.....	111
14. Benefits of wood-based materials.....	114
15. Limitations of wood.....	116
16. Products to incorporate VTC wood.....	118
17. Advantages to the commercialization/use of VTC wood.....	122
18. Barriers to the commercialization/use of VTC wood.....	125

# COMMERCIALIZATION POTENTIAL OF VISCOELASTIC THERMAL COMPRESSED (VTC) WOOD

## CHAPTER 1 - GENERAL INTRODUCTION

The global forest resource is in a state of change. In most parts of the world, large-diameter, old growth trees are no longer available for harvest. The majority of remaining old growth forests in North America has been set aside for preservation, while plantation forests are on the rise. The volume of wood fiber necessary to satisfy global demand is rising steadily with world population. The combination of increased demand for wood fiber and restrictions on natural forest logging has placed great emphasis on the utilization of plantation fiber. Unfortunately, softwood species grown in short-rotation plantations tend to produce trees with large juvenile wood cores resulting in wood with relatively low strength and stiffness, which is unsuitable for structural applications.

The increased use of logs from plantations is potentially problematic for the production of certain composite wood products, such as laminated veneer lumber (LVL). LVL is composed of layers of veneer; some of the layers need

to be high-grade veneer in order to attain required strength and stiffness values. Due to the limited availability of large-diameter logs, high-grade veneer is not as prevalent as it once was. In an attempt to combat this availability issue, many have turned to plantation-grown logs for a solution. Unfortunately, high strength and stiffness values are difficult to attain from plantation logs due to the high proportion of juvenile wood they contain. In many parts of the world, plantation trees are harvested when they're less than twenty years old, which means they contain a large proportion of juvenile wood. Juvenile wood is markedly weaker and less dense than mature wood. Since large-diameter logs are often difficult to attain, and plantation-grown logs contain a high proportion of juvenile wood, an alternative way to acquire high-grade veneer became necessary. One way to increase the available volume of high-quality veneer is to modify plantation fiber to increase its strength and stiffness, which can be done by wood densification. A variety of densification methods exist today, which achieve wood densification through compressive, thermal, and mechanical means. The Viscoelastic Thermal Compression (VTC) process is one method that can increase the density of low-density wood species by three to four times. Through the use of VTC technology, plantation fiber can be turned into something possessing mechanical properties above and beyond what is necessary for structural applications.

## OBJECTIVES

This thesis will identify potential commercial applications and markets for VTC wood.

The specific objectives are:

- Identify potential commercial applications for VTC wood.
- Understand potential advantages and limitations to VTC commercialization.

In order to achieve these objectives, personal interviews were conducted with individuals in the forest products industry and with building design and construction professionals. The resulting qualitative data was then analyzed to fulfill the objectives.

## CHAPTER 2 – THEORETICAL BACKGROUND

### **State of the World's Forests**

In 2005 there were approximately 4 billion hectares of forest area worldwide, which covered more than 30% of the total land area (Food and Agriculture Organization [FAO] 2009). Close to 4% of total forest is plantation forests (FAO 2009). The percentage of plantation forests, when compared to that of natural forests, is expected to increase each year.

Throughout the past few decades, the way in which forests are used and managed has changed worldwide. Due to public awareness and increased utilization of the world's natural forests, old growth large-diameter logs are no longer available for harvest in most of the world. The global resource base of woody fiber has shifted from large old-growth forests to small, quickly grown, and intensively managed plantation forests (FAO 2009). The area covered by natural forests has decreased in many regions, while the area of plantation forests has increased (FAO 2009). In the context of this thesis, "plantation forests" are defined as "forests of introduced and/or native species established

through planting or seeding mainly for production of wood or non-wood goods” (FAO 2009). The current state of two forest regions, where plantations are prevalent, will be discussed in turn. A brief discussion of North American forests will follow, which will serve as a comparison.

- (1) Asia and the Pacific account for 18% of the global forest area. Areas previously managed for wood supply in natural forests have significantly decreased, while the planting of plantation or “farm” forests has been on the rise. The decreased use of natural forests for wood production is due to the complexity and high costs associated with natural forest management. The majority of planted forests are located in Australia, New Zealand, China, India, Indonesia, and Vietnam (FAO 2009).
- (2) Latin America and the Caribbean account for 22% of the global forest area, which has been slowly decreasing for the past ten years. In an effort to combat forest losses, favorable government incentives and policies have driven plantation development. The increase of plantation forests has been led by the private sector, who benefit due to fractional reimbursement of costs, tax breaks, and low-interest loans for small owners (FAO 2009). Despite its recent growth, the planted forest area in Latin America and the Caribbean is only 5% of the world’s total (FAO 2006b). However, this figure is expected to increase dramatically by

the year 2020 due to the region's abundance of suitable land and favorable investment climate (FAO 2009).

- (3) North America accounts for 17% of the global forest area and contains some of the world's most productive forests. Since 2005, the rate of deforestation throughout North America has decreased, while the United States experienced a net gain in forest area (FAO 2009). North America is the world's largest producer, consumer, and exporter of wood products (FAO 2009). However, wood products produced in the United States are almost exclusively from natural forests; plantations are still few and far between. If North America continues to experience net gains in forest area and decreasing levels of deforestation, we may never see an increase in plantation forest area.

### **Global Demand for Wood Fiber**

There are several factors affecting the long-term global demand for wood fiber, such as world population, GDP, increase of developing economies, environmental policies and regulations, and a decline in harvesting from natural forests combined with an increase in plantation forests (FAO 2009).

The world population is expected to grow from 6.7 billion in 2010 to 8.2 billion in 2030, while the global GDP is expected to increase from US\$55 trillion in 2010 to US\$100 trillion in 2030 (FAO 2009). Many nations throughout the

world are becoming more developed with an increased standard of living and need for wood and paper products. The environmental policies and regulations in several countries greatly restrict the ability to use the forest for wood production. Additionally, energy policies are encouraging the use of woody biomass for fuel. In 2005, the world production of wood products was approximately 417 million m<sup>3</sup> and the world consumption was 421 million m<sup>3</sup>. By 2030, these numbers are expected to rise to 603 million m<sup>3</sup> and 594 million m<sup>3</sup>, respectively (FAO 2009). The highest growth in production is expected to occur in the Russian Federation, Eastern Europe, and South America, while increased consumption is expected to dominate in Africa, Asia, and the Pacific (FAO 2009).

The increased reliance on plantation fiber in the years to come is not a perfect solution to mounting wood demands, however. Trees in a naturally generated forest take anywhere from 35 to 150 years to reach a harvestable age, while those grown in a plantation can be harvested in less than 20 years. The shortened time to harvest is a substantial benefit of plantations, but “the demand for certain types of wood products cannot be met with trees that are so rapidly grown” (Kamke and Sizemore 2008). Trees grown in short rotations have a higher percentage of juvenile wood than trees grown in longer rotations, which can result in undesirable wood properties. As of 2005, there

were more than 110 million hectares of forest plantations worldwide (FAO 2006). Approximately 20% of global forest plantations are comprised of *Pinus* species; the most common of which is radiata pine (*Pinus radiata*) (FAO 2006). Radiata pine's quick growth and desirable pulp qualities have caused it to be planted throughout much of the world (Kamke 2006). Like radiata pine, the majority of fiber produced from plantations is suitable for papermaking and biofuel feedstock, but is not usable in structural applications due to its low density and inadequate mechanical properties (FAO 2009; Kamke and Sizemore 2008). The increasing global population and resulting dependence on plantation fiber calls for some sort of solution in order to meet global demands for structural wood products.

To many, the abundance of plantation fiber does not seem like a solution to help satisfy the global demand for structural forest products. It is true that most plantation fiber cannot be used for structural applications in its natural state, however the fiber can be modified and then used in structural applications. Wood fiber modification aims to increase the wood's strength and stiffness. One such approach of modification is wood densification, which will be discussed in detail below.

## **Methods of Wood Densification**

Regardless of the process used to achieve wood densification, the goal is the same: enhance the strength and stiffness of low-density wood species. Wood densification can occur through various compressive, thermal, and mechanical means. In addition, wood “can be densified by impregnating its void volume with polymers, molten natural resins, waxes, sulfur, and even molten metals, with subsequent cooling to solidify the impregnant” (Kamke and Sizemore 2008). Wood can also be densified by compressing it in the transverse direction without causing damage to the cell wall (Kollmann et al. 1975). The concept of densifying wood without the use of chemicals has existed since the early twentieth century (Sears 1900; Walch and Watts 1923; Olesheimer 1929; Brossman 1931, as cited in Kamke 2006), however, these processes were not adopted by the industry due to insufficient consideration of the final product’s dimensional stability and plasticization after processing (Kollmann et al. 1975; Kamke and Sizemore 2008).

Over the years, a variety of densified wood products have been produced worldwide. Both compressed solid wood products and laminated compressed wood have been produced in Germany. These products are called Lignostone (compressed solid wood) and Lignofol (laminated compressed wood); similar products called Jicwood and Jablo have been made in England (Kamke and

Sizemore 2008). Products densified with resins have been made in both the United States and Germany, which are called Compreg (Stamm and Seborg 1941, as cited in Kamke and Sizemore 2008) and Kunstharzschichtholz (Kollmann et al. 1975, as cited in Kamke and Sizemore 2008), respectively. Another U.S.-made densified wood product, called Staypak, is produced by compressing wood at or below the moisture content it will experience in its end use (Kamke and Sizemore 2008). In addition to the products mentioned above, numerous studies exploring the stabilization and densification of wood have been performed (Kamke and Sizemore 2008).

The Viscoelastic Thermal Compression (VTC) process is a recently patented process developed to densify wood, and is discussed in detail below.

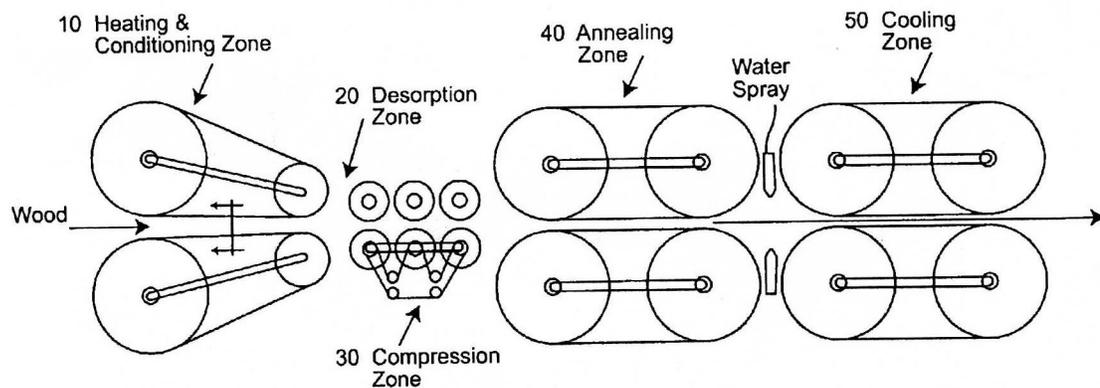
### **Viscoelastic Thermal Compression (VTC) Process**

The VTC process uses heat, steam, and mechanical compression to turn virgin wood into VTC (densified) wood. The process is unique in that it does not damage the micro-cellular structure of the wood (Kutnar and Sernek 2007). The VTC process can be applied to veneer, structural lumber, or strand composites (Kamke 2006). The resulting product has increased density, strength, and stiffness values compared to those of untreated wood

(Kamke and Sizemore 2008). Depending on the VTC wood's end use, the producer can customize the process in order to attain the required properties. The VTC process can be performed on any wood species, but was initially developed to improve the properties of structurally unsuitable species, such as low-density species often grown in plantations.

Kutnar and Sernke (2007) described the VTC process in five main steps (Figure 1). 1) The wood is heated and conditioned to a temperature between 150 and 190° C and a high moisture content (Gabrielli and Kamke 2008). This is done until the wood reaches or goes beyond its glass transition temperature. 2) The bound water is removed from the cell wall. Removal of the bound water allows the wood to be compressed without damaging the cell wall structure. An intact cell wall is of great importance because larger strength and stiffness values are achieved. 3) After the bound water is removed, the wood is compressed perpendicular to the grain. This is done while the wood is still at its glass transition temperature, and results in an increase in density. 4) The wood is annealed so that the internal stresses can relax, and to reduce the hygroscopicity of the wood. 5) The wood is cooled below its glass transition temperature and the moisture content is increased. The wood is conditioned to the ambient temperature and humidity. From start to finish, the VTC process takes approximately ten to fifteen minutes. VTC

wood has a low moisture content with a reduced affinity for water; density is increased by 100 to 200%; stiffness and strength are increased (Table 1) (Kamke and Sizemore 2008); and the veneer is compressed by one third to one fourth of its original thickness.



**Figure 1.** VTC Continuous Press (Kamke and Sizemore 2008)

**Table 1.** Mechanical properties for VTC wood and commonly used species

	VTC wood Any species	poplar <i>Populus spp.</i>	hard maple <i>Acer saccharum,</i> <i>Acer nigrum</i>	Douglas-fir <i>Pseudotsuga</i> <i>menziesii</i>
Property	Value	Value	Value	Value
Density	44 to 81 pcf	24 to 28 pcf	40 to 44 pcf	29 to 31 pcf

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<b>MOE</b>	2.0 x 10 <sup>6</sup> to 7.0 x 10 <sup>6</sup> psi	1.1 x 10 <sup>6</sup> to 1.4 x 10 <sup>6</sup> psi	1.6 x 10 <sup>6</sup> to 1.8 x 10 <sup>6</sup> psi	1.5 x 10 <sup>6</sup> to 2.0 x 10 <sup>6</sup> psi
<b>MOR</b>	3.0 x 10 <sup>4</sup> to 6.0 x 10 <sup>4</sup> psi	6.8 x 10 <sup>3</sup> to 8.5 x 10 <sup>3</sup> psi	1.3 x 10 <sup>4</sup> to 1.6 x 10 <sup>4</sup> psi	1.2 x 10 <sup>4</sup> to 1.3 x 10 <sup>4</sup> psi
<b>Hardness</b>	2.2 x 10 <sup>3</sup> to 6.5 x 10 <sup>3</sup> psi	0.2 x 10 <sup>3</sup> to 0.3 x 10 <sup>3</sup> psi	2.7 x 10 <sup>3</sup> to 4.9 x 10 <sup>3</sup> psi	1.6 x 10 <sup>3</sup> to 2.3 x 10 <sup>3</sup> psi

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### **Advantages of VTC Wood**

There are several advantages to the production and use of VTC wood. (1)

The VTC process was originally developed for the utilization of low quality and structurally unsuitable wood fiber, which is in line with the changing forest resource. The scarcity of large diameter, mature logs in the marketplace means that producers of structural materials are limited to small diameter logs, whose fiber lends itself well to the VTC process. Logs as small as four inches in diameter can be used. (2) The VTC process' ability to use low strength plantation fiber is highly beneficial due to the short rotation time of plantation forests. Fiber grown in plantations can be harvested as early as ten years of age, compared to 30 years or more for trees grown in natural forests. (3) The utilization of plantation fiber reduces the land base required to provide a mill with raw material. (4) The VTC process can be performed on any wood

species, which allows producers to vary their raw material species depending on cost and availability. (5) Since the VTC process increases the density, strength, and stiffness of the wood, it is possible to create structural products with smaller dimensions compared to wood products currently on the market. A composite containing VTC wood would require less volume of undensified wood than is presently required. (6) Another benefit of the VTC process is the producer's ability to customize the process. The temperature, pressure, and compression can be altered in order to produce material with a specific density. (7) Since the VTC process only utilizes mechanical compression, heat, and steam to densify wood and does not include the incorporation of chemicals, the process is considered "green." This is extremely beneficial to the future adoption and use of VTC wood due to the ever-increasing importance of "green" and sustainable products worldwide. (8) The final product produced by the VTC process is very smooth and darker in color than the raw material, which is desirable in certain applications. (9) In addition, the product emerges from the process with a very low moisture content. This may eliminate the need for an additional dryer in facilities with a continuous VTC machine. (10) The final advantage of VTC wood is its potential to capture a portion of the steel market. The strength to weight ratio of VTC wood is greater than that of steel, which means structurally VTC wood could replace steel in some applications.

### **Disadvantages of VTC Wood**

In addition to the advantages listed above, there are a few disadvantages to the production and use of VTC wood. (1) The exact figures are still unknown, but the VTC process will add significant cost to finished products. High costs will stem from two sources: production (e.g., energy) and raw materials. Of the two expenses, raw material costs are of greatest concern. From the time the raw material enters the VTC process to the time it exits as a finished product, the void spaces in the wood have been eliminated. As a result, the volume of the finished product (the output) is approximately one half the volume of the raw material (the input). This means that a greater amount of raw material (and a greater amount of money) is required to produce a VTC wood product than is required to produce a conventional wood product. (2) An adequate raw material supply may be difficult to secure due to the volume loss that occurs during the VTC process. One-half unit of output from one unit of input means input must be doubled to two units in order to produce one unit of output. In other words, a greater amount of raw material is needed to produce a VTC wood product, which could be difficult to find. (3) The finished product of the VTC process swells when it comes in contact with water. Dimensional stability and swelling are issues, and limit its use to indoor applications. It is possible to add phenol formaldehyde (PF) to the VTC process in order to

make it more dimensionally stable. However, the addition of PF will increase the cost of the finished product and decrease the product's "greenness."

### **Uses for VTC Wood**

VTC wood was originally developed for use as a component in an engineered wood composite. Its high strength and stiffness values make it ideal for structural applications, but non-structural uses are also possible. Possible applications for VTC wood include laminated veneer lumber (LVL), oriented strand board (OSB), plywood, I-joists, glulam beams, concrete forms, furniture, flooring and underlayment, siding and roofing, and packaging. Even though the VTC process increases manufacturing costs, only a small amount of densified material may be needed to dramatically increase a product's mechanical properties. For example, one veneer of VTC wood on the top of a glulam beam and another veneer on the bottom may be all that is needed to make a much stronger beam, while reducing the amount of undensified wood necessary. Four products that could benefit from the incorporation of VTC wood will be considered below.

### **Existing Products Review**

#### *Glulam Beams*

Glulam beams are engineered wood products comprised of several layers of dimension lumber (called lams), which are glued together with a strong, waterproof adhesive to form a single structural member (Bowyer et al. 2003, Roos et al. 2009). Individual lams are typically two inches or less in thickness, and can be a variety of species (Engineered Wood Association [APA] 2008). Glulams can be designed with specific strength, length, and shape characteristics, depending on their designated end use. The majority of glulams produced are straight, but curved beams can be produced for use in custom applications.

In 2009 annual glulam production in the U.S. and Canada was 184.6 million board feet, which was 33.4% less than 2008. This decrease is attributed to the weak housing market and decreasing nonresidential construction market in 2009 (APA 2010a). The struggling housing market directly impacts glulam production because over half of glulam beams produced are for beams and headers in new homes (APA 2010a).

In 2008, approximately 37% of glulams produced were used as floor beams, 26% were used in commercial applications such as office buildings and schools, 19% were used as garage door headers, 11% were used as window

and door headers, and the remaining 7% were used as roof beams and in various industrial applications, such as bridges, utility poles, and marinas (Roos et al. 2009). Glulam beams are a viable alternative to steel and solid sawn wood products.

Since glulam beams are load-bearing members, they must be produced from high-quality, strong lamstock lumber. The various lams within a single glulam are not homogeneous; the lams on the top and bottom of the beam are the strongest because that is where the maximum tension and compression stresses occur (APA 2008). This lamstock placement allows for optimal utilization of the wood: higher-grade lams are used for the outside of the beam, while lower-grade lams are used toward the inside. Due to market demands, a glulam beam with laminated veneer lumber (LVL) on the top and bottom of the beam was created. These beams, called hybrid beams, have higher strength ratings than traditional glulam beams, and are typically used to support wood I-joist floor framing (APA 2008).

Glulam beams are good candidates for incorporation of VTC wood. Similar to the hybrid beams with LVL, VTC wood could be glued to the top and bottom of a glulam beam. The VTC wood would give the beam increased MOE and

MOR values, which may reduce the amount of undensified wood necessary. In addition, the new glulams could be used in applications where conventional glulams are unable due to inadequate structural properties.

### *Laminated Veneer Lumber*

Laminated veneer lumber (LVL) is a composite product consisting of thin veneers bonded together. All veneers are glued so their grain runs parallel to the long direction. Once the veneers are pressed together to form a billet, the billet is cut to the desired dimensions. The dimensions depend on the end construction application (APA 2010*b*). Within a billet of LVL, the veneer layers are not homogeneous. The veneers on the top and bottom of the billet are the highest grade because that is where the maximum tension and compression stresses occur.

In 2009 annual LVL production in the U.S. and Canada was 32.7 million cubic feet, which was 37% less than 2008 (APA 2010*a*). The large decrease in LVL production can be explained by the fact that approximately one-third of the volume of LVL produced goes to I-joist flanges, while the rest goes to beams and headers. All three of these products are used primarily in new home construction.

According to a report done by APA in 2005, the main problem with LVL produced today is that the average veneer grade has decreased significantly in the past ten years. This is of concern because high-grade veneers are necessary in products such as LVL due to product strength requirements. In the same report, manufacturers using LVL in molding and millwork applications rated “surface smoothness” as the most problematic characteristic (APA 2005). Surface smoothness is especially important in molding and millwork due to the large amount of machining and detailing that takes place.

VTC wood could easily be incorporated into an LVL product. Since both LVL and VTC wood are made from veneer, it would be fairly straightforward to incorporate a few plies of VTC wood into a billet of LVL. The incorporation of VTC wood in LVL would help alleviate LVL’s two main problems: low grade veneers and rough surfaces. VTC veneers could be placed on the top and bottom of the billet, thus improving both veneer grades and surface quality.

*Concrete Forms*

A concrete form is a panel product used as a guide when pouring concrete. Concrete forms used in the U.S. are typically made from aluminum or plywood with a high-density (HDO) or medium-density overlay (MDO). In 2001, domestic HDO and MDO plywood made up 41% of the U.S. concrete form market, aluminum made up 39%, and B-B Plyform (B-B Plyform is a plywood panel made with B-grade veneer on the front and back, which is sanded on both sides and treated with a release agent) made up 16% (APA, 2002). According to the APA's Concrete Form report (2002), B-B Plyform and plywood concrete forms have significant problems, which has led to the increased use of both aluminum forms and imported forms. The main problems resulting from the use of plywood forms compared to metal or imported forms were fewer reuses, a poorer concrete finish, and inconsistent quality; the reasons for concrete form type used were more dependent on surface quality than price and other factors (APA, 2002). Well-performing concrete forms must be smooth, consistent across the face, and dimensionally stable.

The addition of VTC wood to concrete forms would offer several advantages over conventional concrete forms. As mentioned above, one of the major problems with wood concrete forms is a poor concrete finish as compared to aluminum forms. Due to the smooth surface of VTC wood, a smooth concrete

finish would be easily attainable. In addition, the increased hardness of VTC wood over regular wood could translate into more pours from each concrete form.

### *Flooring*

Over the past two decades, wood flooring has gained significant market share in the domestic floor coverings industry. While carpet and rug coverings maintain the greatest share of the overall flooring market, they have lost approximately eight percent of the market to wood flooring over a twenty-year period. This loss in market share is not temporary; wood flooring is expected to gain additional market share over the next several years (Bond et al. 2007). Within the category of wood flooring, there are many different types: softwood flooring, hardwood flooring, and composite wood flooring. Hardwood flooring comprises 85% of the total solid wood flooring market (Bond et al. 2007), while composite flooring options have taken off in North America over the past twenty years. Between 1988 and 2002, the amount of wood composite flooring grew from 10 to 58 percent of the total wood floor coverings sold (Blanchet et al. 2006). The increasing popularity of composite wood flooring could easily lend itself to the incorporation of VTC wood. Rather than using a face veneer of oak or maple, VTC wood could be used. In this way, the face of the composite flooring would have increased durability, hardness, and

strength properties. In addition, VTC wood's smooth surface is well suited to flooring use; no additional sanding or smoothing would be necessary. By installing composite flooring made with VTC wood, consumers could gain a stronger, more scratch-resistant floor.

In order for VTC wood to be incorporated into an existing product, it must be studied and analyzed from a business perspective. New Product Development (NPD) is a tool that can be employed to move VTC wood beyond the lab and into the market.

### **New Product Development**

New Product Development (NPD) is both extremely important to the firm's success and extremely difficult to perform effectively. For many companies, the development and introduction of new products is critical for survival (Schmidt et al. 2009), yet has been described as "one of the riskiest, yet most important endeavors of the modern corporation" (Cooper 1993, p. 4).

Unfortunately, the vast majority of new products that enter the NPD process are either terminated or do not succeed commercially (Booz-Allen and Hamilton 1982). According to Cooper and Kleinschmidt (1986), most new products are unsuitable for commercialization. In order for companies to succeed at NPD, they must employ a systematic new product process to steer

and assist the new product project from idea to launch (Griffin 1997; Cooper 1988). Numerous studies have shown a strong relationship between the utilization of a stepwise NPD process and new product success (Hart et al. 2003; Cooper 1994; Cooper 1990; Cooper 1988). In addition, firms that maintain an up-to-date NPD process hold an advantage over those firms that let their NPD processes become obsolete (Griffin 1997).

#### *New Product Development Process*

Regardless of the specific NPD process a firm uses, the vast majority of NPD processes follow a linear and sequential flow of development and evaluation (Cooper 1990). It is important to note, however, that the activities within each stage are far from linear; the stages are cross-functional, overlapping, and activities are often done in parallel (Cooper 2008). Generally speaking, a new product development process is based on a series of development stages combined with a series of evaluation stages (Hart et al. 2003, Cooper 1990). The evaluation stages have been termed gates (Cooper 1990) or convergent points (Hart 1993), “where GO/KILL/HOLD/RECYCLE decisions are made on projects” and “the quality of execution of process activities is ensured” (Cooper 1988, p. 244). Gates often need extra attention due to the fact that they are one of the weakest areas in NPD (Cooper 2008); only 33% of firms have strong and meticulous gates throughout the entire NPD process (Cooper et al.

2005). The evaluation that takes place at the gates requires the collection and analysis of information against predetermined criteria. In order to ensure consistency from one project to another, the screening criteria must be standardized (Schmidt et al. 2009; Cooper 1988). Another way to look at the evaluation gates is as a quality control mechanism. Before the NPD project is allowed to progress to the next step in the process, the gate makes sure essential tasks have been completed, that they were executed properly, and that the project still has commercialization potential (Cooper 1988).

Extensive research has focused on the types of information used in the evaluative stages (Cooper 1990; Cooper 1988), but little work has been done regarding the criteria against which the information is measured (Schmidt et al. 2009; Cooper and de Brentani 1984). Criteria are helpful in that “they can help reduce managerial uncertainty and can identify areas where additional attention and resources are needed. Furthermore, they can strengthen the strategic decision-making process of the firm by helping management develop and can deploy the right competencies and resources across the NPD effort” (Hart et al. 2003, p. 23). When properly utilized, criteria are a very important piece of the NPD process. Nevertheless, it is essential that the criteria used to evaluate a new product at the various evaluation gates be identical to the

criteria used to assess the product's performance after launch (Hart et al. 2003).

To better understand the criteria used by companies during the NPD process, Hart et al. (2003) surveyed firms involved with the development and manufacture of industrial goods in the Netherlands and the UK. Determining the specific criteria used at the different evaluation gates in the NPD process was the main goal of the study. The study's results showed that during the concept screening evaluation gate, for example, respondents most frequently used product performance, customer acceptance, market potential, and technical feasibility as evaluation criteria (Hart et al. 2003). This type of information is helpful when trying to understand not only *if* companies utilize a NPD process, but also *how* they measure the information gathered along the way.

Several variations of the NPD process have been developed and utilized over the years, such as the Stage-Gate® (registered trademark of Robert G. Cooper and the Product Development Institute, <http://www.stage-gate.com>) system (Cooper 1990) and the basic NPD process as described by Crawford and Di Benedetto (2008). Although companies customize and often create

their own NPD processes, most are somewhat similar to the Stage-Gate system. In general, Stage-Gate systems have between four and seven stages and gates (Cooper 1990); an example of one such system is shown in Figure 2. As a firm moves along the NPD process each stage is more expensive than the one prior, but because better information is available, the firm is able to minimize risk (Cooper 2008; Cooper 1990). The activities within the stages are accomplished by a team of people from across the organization; no department is solely responsible for a particular stage (Cooper 2008). Commonly used stages include idea generation, preliminary assessment, detailed investigation (business case preparation), development, testing and validation, and the full production and market launch (Hart et al. 2003; Cooper 1990).

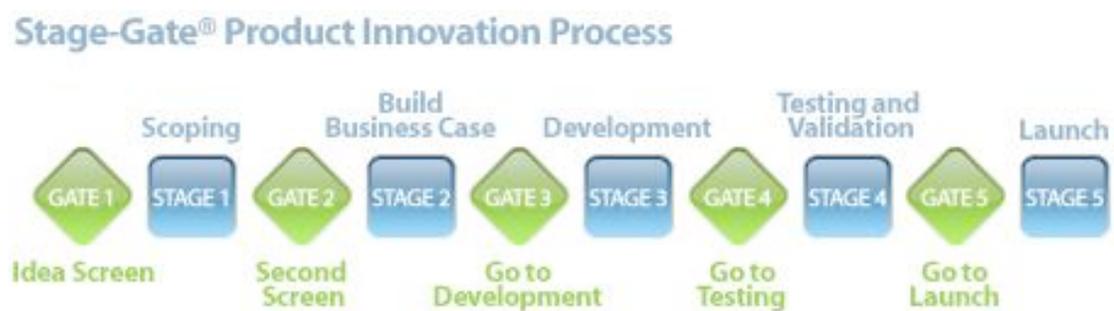


Figure 2. The Stage-Gate® New Product Process (Cooper 2010, <http://www.stage-gate.com/index.php>)

After each stage an evaluation (gate decision) takes place: the goal of the gate is to determine if the new product should advance to the next

development stage or be terminated. When a new product is in the initial stages of development, the gates are based on fairly abstract and incomplete information. However, as the new product progresses through the various development stages, the information used in the gates becomes much more sophisticated and defined (Hart et al. 2003). Gates are comprised of three components: deliverables brought to the decision point by the project manager; must-meet and should-meet criteria; and a decision output (GO/KILL/HOLD/RECYCLE) along with an action plan for the next stage in the process (Schmidt et al. 2009; Cooper 2008). Commonly used evaluation gates in a stepwise NPD process are the initial screen, second screen, decision on the business case, post-development review, pre-commercialization business analysis, and post-implementation review. The 'initial screen' gate is meant to eliminate unrealistic ideas; the information available at this point is limited and rudimentary. Further along the NPD process, however, is a gate called 'post-implementation review.' At this gate, the new product's performance in the market after launch is analyzed. In this stage of the NPD process, the information generated is much more thorough; it is composed of customer opinions, buying behavior, performance of the product in service, production, and delivery (Hart et al. 2003; Cooper 1990).

### *Concept Testing*

The basic NPD process as described by Crawford and Di Benedetto (2008) is comprised of five phases: opportunity identification and selection, concept generation, concept/project evaluation, development, and launch. For the purposes of this study, the concept evaluation stage is the focus. During this stage, the firm evaluates the concepts generated in phase two. The concepts are evaluated based on marketing, technical, and financial criteria, and the best two to three move on to the development phase (Crawford and Di Benedetto 2008). Several activities occur during the concept evaluation stage, but the focus here is concept testing. Concept testing is just one method used to incorporate consumer input in the NPD process; other methods are beta testing (Dolan and Matthews 1993), the lead user method (Urban and von Hippel 1988), consumer idealized design (Cincianntelli and Magdison 1993), and Quality Function Deployment (QFD) (Sullivan 1986). Concept testing was chosen for this study due to the fact that it is often utilized alongside early prototypes, and because it can be applied to industrial products (Kaulio 1998). According to Ulrich and Eppinger (2008), the principal benefit of concept testing is the feedback received from actual customers or users of the product in question.

Due to the exploratory and often qualitative nature of concept testing, it is essential to interview as many stakeholders as possible associated with the proposed product (Patrick 1997). Those who will be involved in the purchase or use of the product or how it might be improved must be consulted during concept testing (Crawford & Di Benedetto 2008). The vast majority of concept testing occurs through personal contact, such as direct interviewing or telephone interviews (Crawford & Di Benedetto 2008). Even though concept testing can be done over the phone, face-to-face interviews are ideal because they give the interviewee an assurance of confidentiality, the option to ask questions if something is unclear, and the ability to see a physical sample of the product (Crawford & Di Benedetto 2008, Patrick 1997). The qualitative information gathered through open-ended discussions with interviewees may be the most valuable result of concept testing (Ulrich & Eppinger 2008), since the goal is to explore what people are doing and thinking, rather than taking a poll (Crawford & Di Benedetto 2008).

Prior to asking questions of the interviewee, it is important to communicate the concept. This can be done in a variety of ways, from a verbal description of the product to the presentation of a working prototype (Ulrich & Eppinger 2008). The order in which information is gathered during a concept testing interview is important. First, the interviewer should acquire background

information from the interviewee. Questions about how the interviewee currently tries to solve his/her problems, their openness to change, and benefits they seek in current products are all examples of background information. The background information can then be used by the interviewer to assist in the interpretation of the interviewee's comments about the new product concept (Crawford & Di Benedetto 2008). In order to get a feel for the interviewee's take on the product concept, the interviewer might ask if the concept solves a problem; what changes could be made to the concept; what the concept would be used for and why; or what products or processes the concept would replace (Crawford & Di Benedetto 2008).

Once the concept testing interviews are complete, the results must be used with caution. The only real information acquired is an indication of likely product acceptance (Cooper 2001). If the product concept is innovative, new, or unfamiliar to the interviewee, the results may actually understate the product's acceptance (Cooper 2001). This is due to the fact that unfamiliar concepts tend to draw a negative response initially, but the response is often changed with time and exposure (Cooper 2001, Crawford & Di Benedetto 2008). The information gleaned from concept testing should be used to decide whether or not to proceed to the next step of the NPD process.

A phase similar to concept evaluation exists in the Stage-Gate process, which is called the 'detailed investigation' phase. In order to move from this phase to the next, a company must stop at the 'decision on business case' gate to make sure all of the appropriate information has been gathered. As an example, the inputs required for the 'decision on business case' gate may include market analysis, competitive analysis, customer reaction (i.e. concept testing), development appraisal, production appraisal, legal, and financial (Cooper 1990). Key questions to ask in order to gain customer reaction information are: "What is quality in the customer's eyes; what is value to him/her; what are desired price/performance characteristics; what are his/her needs, wants, and preferences; what are useful and unique product benefits, attributes and characteristics; and what benefits will be highly visible—will really jump out at the customer" (Cooper 1994, p. 3)? This gate is of utmost importance because it is the final gate before development, which is the beginning of substantial financial commitments (Cooper 1990). If the information inputted into the gate does not measure up to a company's predetermined criteria (must-meet or should-meet criteria), the new product project should not move forward in the NPD process.

Although extensive research has demonstrated the importance of concept testing (Crawford and Di Benedetto 2008; Cooper et al. 2005; Cicianntelli and Magdison 1993), research has also doubted its usefulness (Tauber 1975). Tauber (1975) argues that the attitudes and intentions gained from concept testing do not relate to a person's adoption behavior later on, and that concept testing fails because it does not measure the two most important factors for new product success: adoption and frequency of purchase.

#### *Role of Marketing in NPD*

In order for a new product to successfully progress from idea to launch, "marketing activities must be an integral and essential part of the new product process" (Cooper 1988, p. 250). Unfortunately, marketing activities are frequently skipped over and/or poorly executed (Cooper 1994; Cooper 1988). Research indicates that the frequency and quality of marketing activities in NPD is closely tied to new product success (Zahay et al. 2004; Cooper 1994; Cooper 1988). Marketers must attain a wide breadth of information to assist with NPD success; one critical type of information is figuring out customer needs, wants, and desires (Zahay et al. 2004; Griffin and Hauser 1993; Dougherty 1989).

### *New Product Success and Failure*

Since the 1960's, many studies have acknowledged the high frequency of industrial new product failure (Booz et al. 1968; Cooper 1979). As a result, tremendous work has been done in an attempt to understand why some products are successful while others fail (Cooper and Kleinschmidt 2000; Cooper 1988; Cooper 1979). One such example is a study by Cooper (1979) aimed to identify the major factors that contribute to a new industrial product's success or failure. This type of study is of great importance to industrial firms because "many of the variables which might separate the 'winners' from the 'losers' are within the control of the firm" (Cooper 1979, p. 93). Cooper (1979) found that the most important dimension of new product success is product uniqueness and superiority. A unique and superior product tends to be very innovative and new to the market; meet the needs of the consumer better than existing products; help the consumer lower costs or do something formerly unachievable; integrate unique features for the consumer; and be of higher quality (more durable, lasts longer, more reliable, stronger) than the competitors' products (Cooper 1979). In addition to product uniqueness and superiority, market knowledge and marketing proficiency is also of great importance to new product success (Cooper 1990; Cooper 1979). Companies with a solid understanding of customers' needs and wants, market potential, buyer behavior, competition, and price sensitivity tended to have success with

their new products (Cooper 1979). Other than being familiar with the keys to new product success, one must also be familiar with its barriers. Cooper (1979) identified three common barriers to new product success: making an expensive product relative to competing products with no economic benefit for the customer; being in a market where many new products are introduced; and being in a market where customers are already satisfied and the competition is fierce. According to Crawford and Di Benedetto (2008), “the biggest cause of new product failure is that the intended buyer did not see a need for the item – no purpose, no value, not worth the price” (p. 191).

Throughout the years, several studies have demonstrated that companies who implement a formal and systematic new product development process experience greater new product success (Cooper 1988; Booz-Allen and Hamilton 1982). Cooper and Kleinschmidt (1986) identified thirteen activities of the new product development process that were either carried out (in the case of new product success) or not carried out/skipped over (in the case of new product failures). The thirteen activities ranged from initial screening to market launch; the activities most often skipped or poorly executed leading to new product failures were initial screening, the detailed market study/market research, and the preliminary market assessment study (Cooper 1988; Cooper and Kleinschmidt 1986).

Once a new product has been launched, firms determine the success or failure of the product in the marketplace. In order to ensure everyone within an organization is on the same page regarding new products, it is essential for each organization to define a product “success” and “failure.” The way to measure new product performance varies from firm to firm and industry to industry. However, the majority of companies measure new product performance on three dimensions: technical, financial, and market-based (Hart et al. 2003; Griffin and Page 1993). Common financial measures of success can be grouped into five main categories: profit, assets, sales, capital, and equity (Hart 1993). Nonetheless, firms that solely employ financial measures to determine new product success have received much criticism (Cooper 2000; Maidique and Zirger 1985); many believe that “softer” measures must also be considered (Hart 1993). In addition to financial measures of success, non-financial measures can also be grouped into five main categories: design, activity, market, technological, and commercial (Hart 1993). Cooper (2000) found profitability, time-to-market, influence on the company, opening up new opportunities, market share, and technical accomplishment to be additional determinants of new product success.

Within the forest products industry, four key factors for successful new product development have been identified (Bull and Ferguson 2006; Crespell et al. 2006; Stendahl et al. 2007). Primarily, the product must have superior customer value compared to competing products. Because this value is in the eye of the customer, market research focused on discovering the customers' needs, wants, and desires is of utmost importance. Secondly, the organization must have a structured NPD process that is backed by the entire company. Without cooperation and endorsement from the entire organization, successful NPD is greatly hindered. Thirdly, the company's culture must have a market orientation. Without a market orientation, organizations will not be attuned to the needs and wants of the customer, making successful NPD difficult. Lastly, senior management must support the NPD process from concept generation to launch.

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CHAPTER 3 – COMMERCIALIZATION POTENTIAL OF  
VISCOELASTIC THERMAL COMPRESSED (VTC) WOOD:  
INSIGHTS FROM THE U.S. FOREST PRODUCTS INDUSTRY

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## ABSTRACT

The increasing demand for forest products and restricted use of natural forests has resulted in a shortage of high-strength wood fiber. The area covered by plantation forests is steadily rising, but the fiber produced by these forests is often unsuitable for high-strength applications. One attempt to combat this problem is the Viscoelastic Thermal Compression (VTC) process, which can dramatically increase the strength and stiffness of any wood species.

In order to take the VTC process to the next step-commercialization, individuals in the forest products industry were interviewed. Opinions, ideas, and insights were gathered from interviewees concerning potential applications for VTC wood, as well as advantages and barriers to commercialization.

## INTRODUCTION

As the global population increases, the demand for forest products increases, and the availability of raw materials decreases. The increased awareness and conflict regarding the environment has resulted in more stringent regulations concerning the use of natural forests. In many regions of the world, the forest industry has turned to plantations to satisfy demand.

The increased use of plantation fiber has stirred controversy surrounding the positives and negatives of plantations themselves. Plantations are very productive and are able to rapidly grow trees in a small land area, but are also water and pesticide-intensive and often do not promote the local wildlife due to the use of non-native species (Juslin & Hansen 2003; World Resources Institute 2007). Short rotation times result in low-density wood that is often weaker and less stable than naturally grown trees due to high growth rate and a high proportion of juvenile and reaction wood.

Decreased strength values are problematic in the production of certain wood composites. Composites such as laminated veneer lumber (LVL) and glulam beams contain wood of varying strength characteristics. Oftentimes, the high-strength pieces required for production of these composite products cannot be found in plantation-grown logs. One way to increase the available volume of high-strength wood is to modify plantation fiber to increase its strength and stiffness. Wood densification is one such approach. In general, wood densification is the process by which wood density is increased by compression of the wood, the impregnation of cell lumens with a fluid substance, or a combination of compression and impregnation (Kollmann et al.

1975). Densification of wood can be achieved by impregnating its void volume with polymers, molten natural resins, waxes, sulphur, and even molten metals (Kultikova 1999). Wood can also be densified by compressing it in a transverse direction under conditions that do not cause damage to the cell wall (Kollmann et al. 1975).

A variety of densification methods exist today, which achieve wood densification through compressive, thermal, and mechanical means. A new densification technology, which is still being refined on a lab scale at Oregon State University, has the ability to turn low-strength plantation fiber into structural material. This technology, called the Viscoelastic Thermal Compression (VTC) process (Kamke & Sizemore 2008), can increase the density of low-density wood species by three to four times. Through the use of VTC technology, plantation fiber can be manufactured into a product possessing mechanical properties above and beyond what is necessary for structural applications in traditional wood-framed construction.

The VTC process uses heat, steam, and mechanical compression to densify wood. The process is unique in that it does not damage the micro-cellular structure of the wood (Kutnar et. al 2009). The VTC process can be applied to

vener, structural lumber, or strand composites (Kamke 2006); the resulting product has increased density, strength, and stiffness values compared to those of untreated wood (Kamke and Sizemore 2008; Kutnar et al 2008). Depending on the VTC wood's end use, the producer can customize the process in order to attain the required properties. The VTC process can use any wood species, but was initially developed to improve the properties of low density, structurally unsuitable species, such as those that are often grown in plantations.

## OBJECTIVES

This study will identify potential commercial applications and markets for VTC wood.

The specific objectives are:

- Identify potential commercial applications for VTC wood.
- Understand potential advantages and barriers to VTC commercialization.

In order to achieve these objectives, personal interviews were conducted with individuals in the forest products industry. The resulting qualitative data was then analyzed to fulfill the objectives.

## THEORETICAL BACKGROUND

### **Global Demand for Wood Fiber**

There are several factors affecting the long-term global demand for wood fiber, such as world population, GDP, growth of developing economies, and environmental policies and regulations. The harvest of natural forests has decreased while harvests on plantation forests have increased; the combination of these two factors has greatly affected the global supply for wood fiber, which has indirectly affected demand (FAO 2009). The world population is expected to grow from 6.7 billion in 2010 to 8.2 billion in 2030, while the global GDP is expected to increase from US\$55 trillion in 2010 to US\$100 trillion in 2030 (FAO 2009). Many nations throughout the world are becoming more developed with an increased standard of living and demand for wood and paper products. The environmental policies and regulations in several countries greatly restrict the ability to use the domestic forests for wood production. Additionally, energy policies are encouraging the use of woody biomass for fuel. In 2005, the world production of wood products was approximately 417 million m<sup>3</sup> and the world consumption was 421 million m<sup>3</sup>. By 2030, these numbers are expected to rise to 603 million m<sup>3</sup> and 594 million m<sup>3</sup>, respectively (FAO 2009). The highest growth in production is expected to

occur in the Russian Federation, Eastern Europe, and South America, while increased consumption is expected to dominate in Africa, Asia and the Pacific (FAO 2009).

The increased reliance on plantation fiber in the years to come is not a perfect solution to mounting wood demands, however. Trees in a naturally generated forest can take fifty years or more to reach a harvestable age, while those grown in a plantation can be harvested in less than twenty years. The shortened time to harvest is a substantial benefit of plantations, but the demand for certain types of wood products may not be met with trees that are rapidly grown. Trees grown in short rotations have a higher percentage of juvenile wood than trees grown in longer rotations, which can result in undesirable wood properties. As of 2005, there were more than 110 million hectares of forest plantations worldwide (FAO 2006). The majority of fiber produced from plantations is suitable for papermaking and biofuel feedstock, but is not usable in structural applications due to its low density and inadequate mechanical properties (FAO 2009). The increasing global population and resulting dependence on plantation fiber calls for some sort of solution in order to meet global demands for structural wood products.

One part of the solution to this problem could be the commercialization of VTC wood. Due to VTC wood's increased mechanical properties, structural wood products could be created from plantation fiber. The advantages of VTC wood are many. Since the VTC process creates a manufactured product, it is able to utilize small diameter, low-density logs that can be grown in plantations with a short rotation time. The VTC process is also customizable; the temperature, steam, and compression can be altered to produce material with a specific density and strength. Another advantage is the ability to manufacture composite products with less material, due to the increased mechanical properties of VTC wood. Lastly, VTC wood may be considered a green product since it is produced with only heat, steam, compression, and a renewable resource.

### **New Product Development**

New product development (NPD), or product innovation, can be defined as the creation of new products. Throughout the years, several NPD processes have been developed; all combine steps, activities, decisions, and goals in one way or another to produce new products. A basic NPD process, developed by Crawford and Di Benedetto (2008), consists of five steps: opportunity identification and selection, concept generation, concept and project evaluation, development (both technical and marketing), and launch. For the

purposes of this study, concept evaluation is the focus. Concept evaluation is the evaluation of new product concepts based on three criteria: technical, marketing, and financial. Generally, the two or three best concepts will be carried to the next step of the NPD process, which is development (Crawford and Di Benedetto 2008).

#### *NPD and Innovation in the Forest Products Industry*

Traditionally, the forest products industry has been more focused on production than on the customer, with a production-oriented, low-cost strategy being the norm (Crespell et al. 2006, Juslin & Hansen 2003). However, a more customer-oriented approach has begun to take precedence (Juslin & Hansen 2003). It has been found that many forest products companies are trying to move toward a market orientation (Cohen & Kozak 2001; Hansen & Juslin 2005; Hansen et al. 2007).

With respect to innovation, the industry is focused on process innovation rather than product or business systems innovation (Crespell et al. 2006, Hansen 2006). Depending on how it is marketed, VTC can be referred to as a product innovation (VTC wood), process innovation (VTC process), or both.

In addition to being more production-oriented and focused on process innovation, the forest products industry is notorious for having a change-resistant culture (Hansen et al. 2007). Resistance to change is present in both the company and the marketplace, and “the bureaucracy of building codes and standards can hamper innovation, and, in turn, the innovativeness of manufacturers” (Hansen et al. 2007, p. 1330).

#### *NPD Processes and Market Research*

There are a significant number of new product development processes used today, which are becoming more complex with time. NPD processes are important because the consistent use of a formal NPD process is often a differentiating factor between a company’s success and failure (Griffin 1997b). Two commonly used NPD processes are those developed by Cooper and Kleinschmidt (1986), (Stage-Gate), and Crawford and DiBenedetto (2006). Though markedly different processes, both include the collection of market research. Market research is a vital component of any NPD process because it serves as “the function which links the consumer, customer, and public to the marketer through information” (Churchill & Iacobucci 2006, p. 7). According to the American Marketing Association, market research is used in

all aspects of marketing, such as product concept testing, pricing, distribution, promotion, buyer behavior, and general corporate research (Churchill & Iacobucci 2006). Market research is able to feed into the NPD process by providing those involved with a better understanding of the opportunities and barriers in the marketplace. Rigorous and thorough market research often contributes to a successful end product created with the customer in mind (Churchill & Iacobucci 2006). In this study, market research was used in conjunction with the concept evaluation step of the NPD process to better understand buyer preferences and opinions regarding VTC wood.

### *Concept Testing*

Regardless of the name it's given, concept testing has been used in one form or another for many years. Business-to-business (B2B) firms consistently engage in concept testing activities; much time is spent talking with customers about problems, needs, suggestions, and new ideas (Crawford & Di Benedetto 2008). According to Ulrich and Eppinger (2008), the principal benefit of concept testing is the feedback received from actual customers or users of the product in question.

Due to the exploratory and often qualitative nature of concept testing, it is essential to interview as many stakeholders as possible associated with the proposed product (Patrick 1997). Those who will be involved in the purchase or use of the product or how it might be improved must be consulted during concept testing (Crawford & Di Benedetto 2008). The vast majority of concept testing occurs through personal contact, such as direct interviewing or telephone interviews (Crawford & Di Benedetto 2008). Even though concept testing can be done over the phone, face-to-face interviews are ideal because they give the interviewee an assurance of confidentiality, the option to ask questions if something is unclear, and the ability to see a physical sample of the product (Crawford & Di Benedetto 2008, Patrick 1997). The qualitative information gathered through open-ended discussions with interviewees may be the most valuable result of concept testing (Ulrich & Eppinger 2008), since the goal is to explore what people are doing and thinking, rather than taking a poll (Crawford & Di Benedetto 2008).

Prior to asking questions of the interviewee, it is important to communicate the concept. This can be done in a variety of ways, from a verbal description of the product to the presentation of a working prototype (Ulrich & Eppinger 2008). The order in which information is gathered during a concept testing interview is important. First, the interviewer should acquire background

information from the interviewee. Questions about how the interviewee currently tries to solve his/her problems, their openness to change, and benefits they seek in current products are all examples of background information. The background information can then be used by the interviewer to assist in the interpretation of the interviewee's comments about the new product concept (Crawford & Di Benedetto 2008). In order to get a feel for the interviewee's take on the product concept, the interviewer might ask if the concept solves a problem; what changes could be made to the concept; what the concept would be used for and why; or what products or processes the concept would replace (Crawford & Di Benedetto 2008).

Once the concept testing interviews are complete, the results must be used with caution. The only real information acquired is an indication of likely product acceptance (Cooper 2001). If the product concept is innovative, new, or unfamiliar to the interviewee, the results may actually understate the product's acceptance (Cooper 2001). This is due to the fact that unfamiliar concepts tend to draw a negative response initially, but the response is often changed with time and exposure (Cooper 2001, Crawford & Di Benedetto 2008). The information gleaned from concept testing should be used to decide whether or not to proceed with the next step of the NPD process-development.

## METHODS AND DATA ANALYSIS

Data for this study were collected by personal interviews, which are a common tool used in qualitative research. In personal interviews, data are collected via a face-to-face or telephone conversation between the interviewer and the interviewee. In this study the interviewer asked questions of the interviewee(s), which were audio recorded. The product concept was communicated with both a verbal description and a working prototype. The recorded responses were then transcribed word for word in order to ensure accuracy.

### **Methodology**

#### *Personal Interviews*

There are several advantages to personal interviews compared to other methods of data collection. First, the direct nature of personal interviews enables the researcher to avoid low response rates synonymous with other research methods (Barriball & While 1994, Goyder 1985). Second, the researcher has the ability to explore the interviewee's attitudes, beliefs, and

motives in more depth compared to other research methods (Barriball & While 1994). Third, researchers may acquire additional information by asking follow-up questions guided by the interview or by interviewees providing additional information in response to questions the researcher did not think to ask. The primary disadvantages are cost and time.

## **Study Design**

### *Interview Protocol Development*

A semi-structured interview, rather than a structured interview, was chosen for this study due to the exploratory nature of the questions. This type of interview was chosen because of the interviewer's ability to ask additional questions spurred by the interviewee's responses; a structured interview only allows the interviewer to ask questions found in the interview protocol.

Prior to beginning the personal interviews, a semi-structured interview protocol was developed. According to Flick (2002), a semi-structured interview protocol serves three main functions in an interview: ensures answers to the main topics are gathered from all interviewees, serves as a guide to keep both

the interviewer and interviewee on topic, and keeps the interview moving forward if dialogue between the interviewer and interviewee lags or stops. The complete interview protocol used in this study can be found in Table 2.

**Table 2.** *Semi-structured interview protocol for forest products industry*

<b>Question</b>
1 What is your job title (production, retail, wholesale, marketing, etc.)?
2 What do you see as the greatest unmet need for your customers?
3 In what applications do your customers find wood limiting because of strength or other properties? What are those limiting properties?
4 What are the greatest objections you receive concerning existing wood products for structural applications? For aesthetic applications?
5 In which existing products do you think VTC wood could be used?
6 Do you have any new product ideas that could incorporate VTC wood?
7 What do you see as advantages to the commercialization and/or use of VTC wood?
8 What do you see as barriers to the commercialization and/or use of VTC wood?
9 What do you consider a “deal breaker” concerning your decision to use or not use VTC wood?

### *Pre-Testing*

Pre-testing of the interview protocol consisted of open-ended, casual interviews with three salespeople in the forest products industry and one venture capitalist. Those interviewed were chosen by convenience sampling, which may not produce the best results but saves on time, money, and effort

(Patton 1990). The interviews provided a means to generate ideas, questions, thoughts, and reactions from key individuals concerning the use and application of VTC wood. The information gathered during pre-testing was utilized to fine-tune the semi-structured interview protocol.

#### *Development of Interview Reference Materials*

An information sheet was created to provide the interviewees with materials to reference during the interview. The information sheet contained facts about the mechanical properties of VTC wood and those of commonly used wood species. Several graphs were also created to visually compare the density and mechanical properties of VTC wood and other building materials. The complete set of interview reference materials can be found in Appendix A. In addition, physical samples of undensified hybrid poplar and hybrid poplar treated with the VTC process were shown to the interviewees.

### **Data Collection and Analysis**

#### *Snowball Sampling*

The interviewees in this study were identified based on recommendations by key individuals in the forest products industry and through the use of “snowballing.” Snowballing is the process of identifying new interviewees based on the recommendations of previous interviewees, and is “based on the premise that members of a rare population know one another” (Lohr 1999, p.403). It’s possible to create a large sample by snowballing; however it is not a probability sample due to the breach of statistical assumptions that occur.

### *Sample Selection*

The first group of interviewees was selected based on their attendance at the North American Wholesale Lumber Association (NAWLA) annual conference that took place in Chicago, Illinois November 5-7, 2009. Each year the NAWLA conference is attended by approximately 1,500 individuals employed throughout the forest products industry. Attendees range from production personnel to sales and marketing associates. A large component of the conference is the Trader’s Market, where companies set up information booths. Conference attendees have the opportunity to see what other companies are doing, learn about new products, and catch up with others in the industry. Since so many people from the forest products industry were in the same place at the same time, the NAWLA conference was an ideal opportunity for data collection.

Two weeks before arriving in Chicago for the Trader's Market, an e-mail was sent to twenty individuals in the forest products industry who planned to attend the conference. The twenty individuals contacted were identified as knowledgeable by those interviewed during pre-testing and by faculty at Oregon State University. The purpose of the e-mail was to secure a few interviews prior to arriving at the conference. A total of ten interviews were conducted at the NAWLA conference: nine in individual interviews and one in a group interview. Two interviewees participated in the group interview. Interviewees included three in manufacturing, two wholesalers, two manufacturer/wholesalers, two distributors, and two treaters (Table 3).

The second group of interviewees was selected based on their proximity to Corvallis, Oregon, and/or the researcher's desire to interview individuals from a wide variety of companies and backgrounds. A total of nine interviews were conducted after the NAWLA conference: three phone interviews and six face-to-face interviews (two face-to-face interviews were also group interviews). Two interviewees participated in one group interview, and three interviewees participated in the second group interview. Phone interviews were minimized because those interviewees were not able to see and touch the working

prototypes. Of those interviewed in the second group, eight were in manufacturing, two in trade associations, and one was an exporter (Table 3).

**Table 3. Forest products interviewees by position and location of interview**

Interviewee Category	Geographic Area of Interview		
	NAWLA	Other	Total
<b>Manufacturer</b>			
<i>General Manager</i>	1	2 <sup>c</sup>	3
<i>Sales Manager</i>	2	0	2
<i>Marketing Manager</i>	0	2 <sup>b</sup>	2
<i>Sales</i>	0	1 <sup>b</sup>	1
<i>R &amp; D</i>	0	3 <sup>c</sup>	3
<b>Wholesaler</b>			
<i>Sales and Marketing Manager</i>	1 <sup>a</sup>	0	1
<i>Sales</i>	1 <sup>a</sup>	0	1
<b>Manufacturer/Wholesaler</b>			
<i>General Manager</i>	1	0	1
<i>Buyer</i>	1	0	1
<b>Distributor</b>	2	0	2
<b>Exporter</b>	0	1	1
<b>Treater</b>	2	0	2
<b>Trade Association</b>	0	2	2
<b>Total</b>	11	11	22

<sup>a</sup>This was a group interview consisting of two people from the same company.

<sup>b</sup>This was a group interview consisting of two people from the same company (one manufacturer marketing manager and one manufacturer sales employee).

<sup>c</sup>This was a group interview consisting of three people from the same company (one manufacturer general manager and two manufacturer R & D employees).

### *Data Collection*

The interviews ranged from twenty minutes to one hour in length, and were digital audio-recorded. Audio recording enabled the researcher to accurately preserve the interview data and to be more immersed in the conversation (Yin 1994). The audio recordings were then transcribed verbatim, and the resulting transcripts were used for data analysis. In total, the transcribed interviews were seventy-four double-spaced pages of text (Arial font, Size 12).

Each interviewee was placed in one of three “interviewee categories”: manufacturing, sales, or other. The “manufacturing” category includes manufacturers, manufacturers/wholesalers, and treaters; the “sales” category includes wholesalers, distributors, and exporters; and the “other” category includes those in trade associations.

### *Data Analysis*

After the interviews were transcribed, an exhaustive list of answers was compiled for each of the nine questions in the interview protocol. Once the list was completed, the frequency of each response was recorded every time an

interviewee mentioned it. This process was completed for each of the nine questions. The end result was a list of the nine questions asked with all corresponding responses, and a frequency of each response. The list was broken down by interviewee category for each question. This method of analysis was deemed appropriate due to the exploratory nature of the research as specified by the objectives.

## RESULTS

The results of the study are presented in the following section. In order to ensure anonymity, all interviewees are referred to by their position within the forest products industry (i.e. manufacturing manager, distributor, exporter, etc.). All results are presented regardless of the frequency of each response. Responses with a frequency of one are considered equally “significant” to those with a frequency of ten, due to the wide range of interviewee background and the potential for VTC wood to be successful in a niche market.

### **Greatest Unmet Customer Needs**

Twenty-two interviewees identified ten different unmet customer needs. A few of the interviewees identified more than one unmet need facing their

customers. All responses are listed in Table 4 from the highest to lowest frequency.

**Table 4.** *Greatest unmet customer needs.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

<b>Response</b>	<b>Interviewee Category</b>			
	<b>Manufacturing</b>	<b>Sales</b>	<b>Other</b>	<b>Total</b>
Product consistency	3	1		<b>4</b>
Product quality	2	1		<b>3</b>
Demand		1	1	<b>2</b>
Maintenance-free products	1	1		<b>2</b>
Achieving increased mechanical props.	1			1
Aesthetics	1			1
Dimensional stability	1			1
Product ability to withstand hurricanes	1			1
Product meets end user's specifications		1		1
Products with desired certification	1			1

The four most frequently reported unmet customer needs were product consistency, product quality, demand, and maintenance-free products. Other reported unmet customer needs were achieving increased mechanical properties, aesthetics, dimensional stability, product ability to withstand hurricanes, product meets end user's specifications, and availability of products with desired certifications (i.e. CARB, FSC, etc.).

Several interviewees reported consistency (of both the product and the supply) as their customers' greatest unmet need:

Consistency. Wood is a natural product...it's not a manufactured product. There's even some species of panels you're not going to get stability out of. I would say the biggest unmet need is consistency and stability for building products that are used today. *Manufacturer/Wholesaler, General Manager*

I think in general I would say a guaranteed supply of consistently low-priced raw material. I really think in the marketplace, as long as what they're buying works for them, what matters the most is price and dependability of the supply. Our biggest concern is availability of the resource that will fit our product. *Manufacturer, General Manager*

In addition to consistency, product quality was reported as an unmet customer need:

Quality. The quality of the veneer, because as the logs have gotten smaller the peels have gotten rougher, the lathes go faster. Finding good, consistent, smooth peels is definitely the hardest thing. *Manufacturer, Manager*

I think there's a huge need in terms of the quality of the material we get...it's degraded over the last twenty years. We're trying to make high quality products with lower quality raw materials. *Manufacturer, Marketing Manager*

I'm going to put the question into the sense of what I'm not getting, versus what they're [my customers] not getting...consistency of the quality of the product. Consistency of quality of the product within the grades is what I'm not getting.  
*Treater*

### **Applications Where Wood is Limiting**

Interviewees were asked to identify applications where wood is limiting, as well as the greatest objections concerning the use of wood in structural applications. Eight different applications were reported (Table 5). The interviewee responses are listed from the highest to lowest frequency.

**Table 5.** *Applications where wood is limiting.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

<b>Response</b>	<b>Interviewee Category</b>			<b>Total</b>
	<b>Manufacturing</b>	<b>Sales</b>	<b>Other</b>	
High strength	4	2	2	<b>8</b>
Dimensional stability	3			<b>3</b>
Fire rating	2		1	<b>3</b>
Spans	1	2		<b>3</b>
Building codes	1		1	2
Cost	2			2
Contact with insects		1		1
Weathering			1	1

According to the interviewees, wood is most limiting in applications associated with high strength, dimensional stability, fire ratings, and long spans. In this context, “strength” refers to a variety of wood properties, such as modulus of rupture (MOR) in bending, compression, tension, and shear. Dimensional stability and spans are also a common issue and can be a restriction when building with wood. Additional reported limitations involve building codes, cost, contact with insects, and weathering. The majority of interviewees stated two or more applications where they find wood limiting.

There are two limiting factors we find...span ratios...and in a ground sill application...strength for compression and bugs.  
*Exporter*

Wood is limiting in everything we do...from quality, availability, the quirky aspects, how it moves, and how our customers use it. But it's also the attraction. *Manufacturer, Sales*

One limiting area of wood would be its bending properties. Quite often we're asked to make a product conform to a curve, and the biggest limiting factor in that scenario is being able to conform wood to a small enough radius without either breaking it or having too much tension. Another problem we have with wood is dimensional stability. *Manufacturer, R&D*

Wood is very limiting in lots of applications. Certainly we've overcome some of those in the last few years, but in some parts of the world you still can't build over two stories with wood.  
*Trade Association*

### Potential Products to Incorporate VTC Wood

Interviewees were asked to identify products that could potentially benefit from the incorporation of VTC wood, as well as any new product ideas. Of all the questions posed to the interviewees, this question resulted in the widest array of responses. On average, each interviewee reported three products they believe could be improved by the addition of VTC wood. Table 6 lists interviewee responses from the highest to lowest frequency.

**Table 6.** *Potential products to incorporate VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

Response	Interviewee Category			
	Manufacturing	Sales	Other	Total
Laminated veneer lumber	5	1	2	<b>8</b>
Concrete forms	3	1	2	<b>6</b>
Flooring	4	2		<b>6</b>
Components for boat/car/train/truck interiors	3		1	<b>4</b>
Doors	3	1		<b>4</b>
Glulams	3		1	<b>4</b>
Plywood	1	3		<b>4</b>
Wood window frames	4			<b>4</b>
Commercial truck/trailer beds	3			3
Crates/pallets/packages	1	1	1	3
Decking	2			2
I-joists	1		1	2

Underlayment	1	1	2
Cabinets		1	1
Furniture			1
Manufactured housing	1		1
Parallel strand lumber (PSL)	1		1

As a whole, the twenty-two interviewees identified seventeen products that could benefit from incorporation of VTC wood. Laminated veneer lumber (LVL) was the most commonly suggested product, followed by concrete forms and flooring. Interior transportation vehicle (boat, car, truck, etc.) parts, doors, glulam beams, plywood, and wood window frames tied for the next most commonly mentioned products.

VTC wood could be used in concrete forms, and some sort of LVL application. It is also possible for wood that gets bonded with steel or something else, such as parts for rail cars. There are also parts that have a plywood core, and they put steel around it. They buy premium panels for the parts encased with steel. *Manufacturer, General Manager*

The number one place, especially in the European market, is in the wood window and door industry. In an area where you need a single piece of wood that has good tension strength, and all of the characteristics that you're trying to work with. When you're doing any engineered wood product, you need something with stability and strength. *Treater*

I would use it [VTC wood] in boats, truck bed decking, Great Dane trailers, and applications like that.

*Manufacturer, Sales Manager*

You're really looking at some sort of product like a high density LVL, a modified glulam, a big I-beam, or maybe a high-strength post. That's where I see it instantly...I don't see it in residential construction except for maybe in a big beam over a garage door or something similar. *Trade Association*

The specialty plywood market, with face veneers, with melamine versus compressed hardwoods versus stripped veneer, that market would definitely use something like this [VTC wood] because this would have an application where the rigidity would allow it to be used for cabinet stock, cabinet frames and things like that. Non-appearance grade where they might be interested in something this hard is a specialty poly-fill plywood that's used for concrete forms...it's pretty expensive, uses a petroleum-based paper, and is not environmentally friendly. Those are two areas where I could see this being used.

*Exporter*

I think if some of our lower grade veneers we currently can't use in LVL were treated with the VTC process, they would become a viable product for use in LVL. *Manufacturer, R&D*

### **Advantages to the Commercialization/Use of VTC Wood**

Interviewees were asked what advantages might occur from the commercialization and/or use of VTC wood. Table 7 lists interviewee responses from the highest to lowest frequency.

**Table 7.** *Advantages to the commercialization/use of VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

<b>Response</b>	<b>Interviewee Category</b>			<b>Total</b>
	<b>Manufacturing</b>	<b>Sales</b>	<b>Other</b>	
Increased mechanical properties	7	3	2	<b>12</b>
Add value to low strength species	4	3		<b>7</b>
Create thinner/lighter products	5	1	1	<b>7</b>
Potential to capture some of steel market	2	1	2	<b>5</b>
Create products with longer spans		2	1	3
Utilize rapidly-grown species	3			3
Increase product density		1	1	2
Open up a new resource pool	2			2
Color change as result of VTC process		1		1
Consistency/uniformity of end product	1			1
Use of local product/resource			1	1

The most frequently reported advantage to the commercialization of VTC wood was increased mechanical properties of products.

The MOR boost is the key. It really buys us a whole heck of a lot, because it allows us to do so much more with our regular stock. We wouldn't have to use a ton of VTC wood; it would just be to supplement our product. *Manufacturer, Sales Manager*

For some applications you might want either LVL or plywood to span a little longer, and for the concrete form you might want a denser surface. *Trade Association*

The possibility of creating wood that's smaller in dimension than what you're currently using that achieves the same or better properties. *Manufacturer, General Manager*

In addition to increased mechanical properties, interviewees also identified the use of rapidly grown, low strength wood species as an advantage to the commercialization of VTC wood.

Taking lower density species and making high quality, strong products. *Wholesaler, Sales and Marketing Manager*

You can take twelve year old plantation poplar and make structural components from it...that's valuable.  
*Manufacturer, General Manager*

It opens up a pool of raw material that currently isn't usable for various applications. You could take a fiber resource base that prior to this process would never have the value or the ability to go into a given application. A lot of these species you're dealing with here, they're a fiber that has very limited application.  
*Manufacturer, R&D*

Other commonly reported advantages to the commercialization and use of VTC wood were the ability to create thinner products, the potential to capture a

portion of the steel market, and the ability to create products with longer spans.

### **Barriers to the Commercialization/Use of VTC Wood**

Interviewees were asked to identify barriers that might hinder the commercialization and/or use of VTC wood. Barriers are important to understand because they can be improved upon or eradicated before VTC wood proceeds to the development step of the NPD process. Table 8 lists interviewee responses from the highest to lowest frequency.

**Table 8.** *Barriers to the commercialization/use of VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

<b>Response</b>	<b>Interviewee Category</b>			
	<b>Manufacturing</b>	<b>Sales</b>	<b>Other</b>	<b>Total</b>
Cost focus of industry/cost of production	10	2	2	<b>14</b>
Industry's resistance to change	8	2	2	<b>12</b>
Raw material supply	3	1	1	5
Dimensional stability	1	2		3
Energy consumption of process	3			3
Volume loss from input to output	2		1	3
Interaction between VTC wood and undensified wood in a composite	1	1		2

Introduction of VTC wood could slow down production process	2		2
Someone could buy VTC technology and shelve it	1	1	2
Brittleness	1		1
Color change as a result of the VTC process	1		1

The two most frequently reported barriers to the commercialization and/or use of VTC wood were the cost focus of the industry/cost of production and the industry's resistance to change. Fourteen interviewees identified cost, while twelve identified the industry's resistance to change as the largest barrier to commercialization.

Cost would be the first hurdle, and the second would be getting market acceptance. Whether it's the builders, or lumbermen, or whatever, they don't care whether the wood cells collapsed or not. They don't care about any of that...they just want to know if the product will perform, or if there's some sort of marketing advantage, whether it's price, installation, whatever it may be. Market acceptance and cost seem like a challenge.

*Distributor*

Number one, probably that it's a new product. This is a very old school industry; everything is grandfathered in.

*Treater*

People in this industry are slow to change to new ideas. Getting people comfortable with it is tough...but on the other hand they did make the move from plywood to OSB. To find people that are willing to take those initial risks...you're going to have to go

to some really major starting points in the construction industry.  
*Manufacturer, R&D*

Number one barrier [to commercialization] is cost...that's what anybody will tell you and it's probably true.  
*Trade Association*

If you compress wood, your yield is maybe half of what your supply was. Plus manufacturing costs, it seems very expensive. From that standpoint, you'd have to have a very special and niche market. *Manufacturer, Sales*

Interviewees also identified raw material supply, dimensional stability, energy consumption of the production process, and the volume loss from input to output as potential barriers to the commercialization of VTC wood.

### **Deal Breaker to Use VTC Wood**

Interviewees were asked to identify a "deal breaker" as to whether they would use VTC wood if it were available in the marketplace. Although similar to barriers, deal breakers differ in that they often cannot be overcome. Table 9 lists interviewee responses from the highest to lowest frequency.

**Table 9.** *Deal breaker to use VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

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**Interviewee Category**

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<b>Response</b>	<b>Manufacturing</b>	<b>Sales</b>	<b>Other</b>	<b>Total</b>
Cost	5	3	1	<b>9</b>
Market acceptance of product	7			<b>7</b>
Raw material supply	1	3	1	<b>5</b>
Exclusivity/licensing of technology	3	1		<b>4</b>
Product appearance/color	3			<b>3</b>
Environmental certification	2			<b>2</b>
Environmental impact of process	1			<b>1</b>
Fire rating	1			<b>1</b>
Glue bonds	1			<b>1</b>

Not surprisingly, interviewees identified the deal breaker “cost” with the highest frequency. Nine interviewees considered cost their only deal breaker or one of several deal breakers regarding the hypothetical use of VTC wood. The other two commonly reported deal breakers were market acceptance of the product and the raw material supply. Another subject of concern was the exclusivity and/or licensing of the VTC technology.

On a purchasing side, or distribution/marketing side, it would be how it would be licensed. How much control can I have over my own destiny, are you going to go sell this to everybody, so that it becomes a commodity and isn't viewed as a value product anymore. So, that's a deal breaker to me.

*Manufacturer, Sales Manager*

The only thing that would make us use it is if it performed and met our customers' specs, and did so in a fashion where we could buy the material and our customers were willing to pay the extra costs to get better performance.

*Manufacturer, General Manager*

Interviewees had contrasting opinions with regard to the finished product's color and overall appearance.

One is the discoloration...that's a definite drawback. I would have a problem because it wouldn't match my other components. *Manufacturer, Marketing Manager*

And then again, the visual side of things...for us, it would be used as a visual member. The darker color could be desirable, depending on what the customer asks for...but the biggest deal with color is consistency. As long as the color is consistent, I could see it being used for products like we're using right now.

*Manufacturer, R&D*

## DISCUSSION

### **Lack of Quality and Consistency**

One of the key findings of this research was the current problem surrounding raw material and forest products quality and consistency. Several interviewees voiced their frustrations with both the deteriorating quality and consistency of forest products, as well as how it negatively affects their

business. Veneer facilities are negatively impacted because smaller logs contain less veneer and cause more wear on the lathe knives; treaters are losing money due to the inconsistent quality of product they're purchasing to treat; composite manufacturers are suffering because it is becoming more and more difficult to produce high-quality products from low-quality inputs. Product consistency is not the only concern: raw material consistency (availability) is also a problem affecting those in the forest products industry. When a production facility's raw material supply is inconsistent, output volume and production schedules are not optimized. Overall, decreasing log sizes and inconsistent raw material supplies are negatively impacting the quality and consistency of products throughout the forest products industry.

The commercialization and use of VTC wood could help alleviate many of the problems surrounding quality and consistency. Since VTC wood is the product of a manufacturing process, the variability associated with log quality would not be as great an issue. In addition, the VTC process would create a more consistent product for treaters, and a stronger, higher-quality product for composite manufacturers. Raw material availability and consistency would be increased due to the predictability of fiber grown and harvested in plantation forests. VTC wood's enhanced mechanical properties would enable products

to be manufactured with greater strength than wood products currently available.

### **Products to Incorporate VTC Wood**

The interviewees identified a wide variety of products that could benefit from the incorporation of VTC wood. Both structural and nonstructural products were mentioned. Structural products, such as LVL, glulams, plywood, concrete forms, and components for transportation vehicles were mentioned with the highest frequency. LVL was likely mentioned most frequently due to the relative ease with which VTC veneers could be incorporated into conventional LVL. The same is true for both plywood and concrete forms. Nonstructural products mentioned were composite flooring, wood window and door frames, crates and packaging, decking, underlayment, and furniture. A few interviewees asked whether VTC wood could be made into 3-D shapes, such as those necessary for transportation vehicle components. This “outside the box” thinking did not occur often, however. Many interviewees only felt comfortable suggesting products that they work with on a daily basis, rather than products unfamiliar to them that could incorporate VTC wood.

The interviewees' hesitation to suggest products unfamiliar to them was not surprising, since it is a common occurrence with radical innovations.

Oftentimes the interviewees did not completely understand the innovation, and therefore held back suggestions that might not make sense. Other times, they had trouble thinking about the product in an actual application since they were limited to the interviewer's explanation and a few small samples.

### **Advantages to the Commercialization/Use of VTC Wood**

The two most commonly mentioned advantages to the commercialization of VTC wood, increased mechanical properties and the utilization of low-value wood species, are also the most apparent. Interviewees seemed intrigued and excited by the possibility of a wood product with the properties attainable through the VTC process. In addition, the possibility of turning a structurally unusable wood species, such as hybrid poplar, into a structural element piqued the interest of several interviewees. Due to the mechanical properties made possible by the VTC process, capturing part of the steel market seemed viable to some. A few of those interviewed stressed that the "ultimate goal" of new forest products is to take as much market share away from steel and concrete as possible. Since the strength to weight ratio of VTC wood is greater than that of steel, this goal could be attainable.

Interviewees considered the time necessary for commercialization as an advantage with respect to nonstructural products. Several of those interviewed believe that a nonstructural product with VTC wood would take significantly less time and scrutiny to commercialize than a structural product with VTC wood. A structural product would take a considerable amount of testing and time in order to be approved for use in building applications. A nonstructural product would not require extensive testing, and would be available for use earlier than a structural product.

### **Barriers to the Commercialization/Use of VTC Wood**

Interviewees had the most similar answers to potential barriers of the commercialization of VTC wood than they did to any other question. More than half of those interviewed mentioned the industry's cost focus and/or the cost of production as a significant barrier to commercialization. In addition to cost, the majority of interviewees believed the industry's resistance to change will be a barrier to both the commercialization and use of VTC wood. Several individuals made reference to the products and methods of doing things in the forest products industry as being "grandfathered in." In other words, people continue to do things a certain way because that's how they've always been

done, rather than because their way is the most efficient or effective. Even though this way of thinking continues to prevail in the forest products industry, some new products have managed to become successful. Oriented strand board (OSB), laminated veneer lumber (LVL), composite flooring products, I-beams, medium density fiberboard (MDF), and composite decking are a few examples of products that were successfully commercialized and are now widely used. Their success can be attributed, in part, to superior performance and/or cost compared to similar products on the market.

In order to circumvent the industry's cost focus, VTC wood might have to enter the market as a specialty product that doesn't compete primarily on price.

This may be the only way to get VTC wood into the hands of design professionals and those in the forest products industry toward the beginning of its commercialization. Since the VTC process is both raw material and energy intensive, competing primarily on price does not seem feasible at first.

However, with time, VTC wood may be in such high demand that it is able to compete in other ways.

### **Deal Breaker to Use VTC Wood**

The “deal breakers” reported by interviewees with the greatest frequency were identical to those mentioned in barriers to commercialization: cost and market acceptance. Since deal breakers often cannot be overcome, extra effort must be expended to minimize the cost of VTC wood and how it is introduced in the market. If the cost of VTC wood products cannot compete with that of similar products, it may be forced to compete in a niche market that is less cost-focused. Unfortunately, cost is still the primary focus for commodity products in the forest products industry. Other commonly mentioned deal breakers were raw material supply and how the VTC technology is going to be licensed. A few interviewees stated they would only consider purchasing the VTC technology if they were guaranteed some level of exclusivity. If the technology was available to all interested companies, it could become a commodity and the original investing company(ies) would not have an advantage in the marketplace. Some interviewees were also concerned with the raw material supply. If VTC wood were to take off, is there enough low-value wood to support demand? Poplar may be inexpensive now, but what if it becomes expensive in the future? These are both questions that need to be carefully considered.

## CONCLUSIONS

VTC wood can both fulfill the needs satisfied by current products and go beyond what's currently available in wood products. Interviewees thought VTC wood could most likely be used in LVL, plywood, concrete forms, transportation components, and flooring. Advantages to commercialization included increased mechanical properties and the utilization of a low-value wood species; barriers to commercialization were the forest products industry's resistance to change and cost focus. Overall, interviewees seemed to think VTC wood would be successful as long as it was not markedly more expensive than similar products.

Before VTC wood's ideal location in the market can be determined, cost of production must be known. If VTC wood is going to cost significantly more than high-grade veneer, for example, it may not be able to compete. If this is the case, VTC wood may be better suited to a specialty product in a niche market. The forest product industry's cost focus will be a significant factor in the success or failure of VTC wood.

In the future, it would be beneficial to conduct additional interviews where the interviewer was equipped with cost information for VTC wood. Samples produced from a continuous process, rather than a batch process, would

present a more accurate representation of the final product's appearance and properties. Prototypes could help interviewees visualize the product and respond to it in a less abstract fashion. It might also be advantageous to have completed all testing on VTC wood prior to conducting more interviews.

## LIMITATIONS

The three major limitations of this study were the interview locations, the interviewees themselves, and the interviewees' lack of understanding of the VTC process. The interviews were limited to Chicago, Illinois and Portland, Oregon. Most of the interviewees interviewed in Chicago were not from the Pacific Northwest, but all of those interviewed in Portland lived there as well. Only one interviewee lived and worked outside of the United States. The interviewees could also be considered a limitation because of the way they were identified. Snowball sampling was used to identify interviewees, but oftentimes the individuals solicited by the interviewer were unresponsive and an interview did not occur. As a result, interviewees with a particular personality or greater interest in VTC wood may have been the ones to consent to an interview. The third limitation was the interviewee's lack of understanding of the VTC process. The VTC process was explained to each interviewee prior to beginning the interview, but some interviewees may have not completely understood and answered based on some level of confusion.

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CHAPTER 4 – COMMERCIALIZATION POTENTIAL OF  
VISCOELASTIC THERMAL COMPRESSED (VTC) WOOD:  
INSIGHTS FROM OREGON DESIGN PROFESSIONALS

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## ABSTRACT

The increasing demand for forest products and restricted use of natural forests has resulted in a shortage of high-strength wood fiber. The area covered by plantation forests is steadily rising, but the fiber produced by these forests is often unsuitable for high-strength applications. One attempt to combat this problem is the Viscoelastic Thermal Compression (VTC) process, which can dramatically increase the strength and stiffness of any wood species.

In order to advance VTC wood from the concept evaluation stage to the development stage, concept testing was conducted with design professionals (i.e. architects, engineers, contractors, etc.). Valuable opinions, ideas, and insights were gathered from interviewees concerning potential applications for VTC wood, as well as advantages and barriers to its commercialization.

## INTRODUCTION

The global population and the demand for forest products are directly linked: as the global population increases, the demand for forest products increases. This increase in demand has a substantial impact on the availability of raw materials. However, factors such as the “green movement” and international trade laws have contributed to more stringent regulations concerning the use

of natural forests. In order to satisfy demand, many regions of the world have turned to plantations.

The increased use of plantation fiber has stirred controversy surrounding the positives and negatives of plantations themselves. Plantations are very productive and are able to rapidly grow trees in a small land area, but are also water and pesticide-intensive and often do not promote the local wildlife due to the use of non-native species (Juslin & Hansen 2003; World Resources Institute 2007). Short rotation times result in lower-density wood that is often weaker and less stable than naturally grown trees due to a high growth rate and a high proportion of juvenile and reaction wood.

Decreased strength values are problematic in the production of certain wood composites. Composites such as laminated veneer lumber (LVL) and glulam beams contain wood with a wide range of strength characteristics.

Oftentimes, the high-strength pieces required for production of these composite products cannot be found in plantation-grown logs. One way to increase the available volume of high-strength wood is to modify plantation fiber to increase its strength and stiffness. Wood densification is one such approach. In general, wood densification is the process by which wood density

is increased by compression of the wood, the impregnation of cell lumens with a fluid substance, or a combination of compression and impregnation (Kollmann et al. 1975).

A variety of densification methods exist today, which achieve wood densification through compressive, thermal, and mechanical means. A new densification technology, which is still being refined on a lab scale at Oregon State University, has the ability to turn low-strength plantation fiber into structural material. This technology, called the Viscoelastic Thermal Compression (VTC) process (Kamke & Sizemore 2008), can increase the density of low-density wood species by three to four times. Through the use of VTC technology, plantation fiber can be manufactured into a product possessing mechanical properties above and beyond what is necessary for structural applications in traditional wood-framed construction.

The VTC process uses heat, steam, and mechanical compression to densify wood. The process is unique in that it does not damage the micro-cellular structure of the wood (Kutnar et. al 2009). The VTC process can be applied to veneer, structural lumber, or strand composites (Kamke 2006); the resulting product has increased density, strength, and stiffness values compared to

those of untreated wood (Kamke and Sizemore 2008; Kutnar et al 2008). Depending on the VTC wood's end use, the producer can customize the process in order to attain the required properties. The VTC process can use any wood species, but was initially developed to improve the properties of low density, structurally unsuitable species, such as those often grown in plantations.

## OBJECTIVES

This study will identify potential commercial applications and markets for VTC wood.

The specific objectives are:

- Identify potential commercial applications for VTC wood.
- Gain insight to the needs and concerns of design professionals to assess their propensity to specify VTC wood.
- Understand potential advantages, barriers, and limitations to VTC commercialization.

In order to achieve these objectives, personal interviews were conducted with design professionals (architects, engineers, contractors, builders, etc.). The resulting qualitative data was then analyzed to fulfill the objectives.

## THEORETICAL BACKGROUND

### **New Product Development**

New Product Development (NPD) is both extremely important to the firm's success and extremely difficult to perform effectively. For many companies, the development and introduction of new products is critical for survival (Schmidt et al. 2009), but has been described as "one of the riskiest, yet most important endeavors of the modern corporation" (Cooper 1993, p. 4). Unfortunately, the vast majority of new products that enter the NPD process are either terminated or do not succeed commercially (Booz-Allen and Hamilton 1982). According to Cooper and Kleinschmidt (1986), most new products are unsuitable for commercialization. In order for companies to succeed at NPD, they must employ a systematic new product process to steer and assist the new product project from idea to launch (Griffin 1997; Cooper 1988). Numerous studies have shown a strong relationship between the utilization of a stepwise NPD process and new product success (Hart et al. 2003; Cooper 1994; Cooper 1990; Cooper 1988). In addition, firms that maintain an up-to-date NPD process hold an advantage over those firms that let their NPD processes become obsolete (Griffin 1997).

### *New Product Development Process*

Regardless of the specific NPD process a firm uses, the vast majority of NPD processes follow a linear and sequential flow of development and evaluation (Cooper 1990). It is important to note, however, that the activities within each stage are far from linear; the stages are cross-functional, overlapping, and activities are often done in parallel (Cooper 2008). Generally speaking, a new product development process is based on a series of development stages combined with a series of evaluation stages (Hart et al. 2003, Cooper 1990). The evaluation stages have been termed gates (Cooper 1990) or convergent points (Hart 1993), “where GO/KILL/HOLD/RECYCLE decisions are made on projects” and “the quality of execution of process activities is ensured” (Cooper 1988, p. 244). Gates often need extra attention due to the fact that they are one of the weakest areas in NPD (Cooper 2008); only 33% of firms have strong and meticulous gates throughout the entire NPD process (Cooper et al. 2005).

Several variations of the NPD process have been developed and utilized over the years, such as the Stage-Gate® (registered trademark of Robert G. Cooper and the Product Development Institute, <http://www.stage-gate.com>)

system (Cooper 1990) and the basic NPD process as described by Crawford and Di Benedetto (2008). Although companies customize and often create their own NPD processes, most are somewhat similar to the Stage-Gate system. In general, Stage-Gate systems have between four and seven stages and gates (Cooper 1990). As a firm moves along the NPD process each stage is more expensive than the one prior, but because better information is available, the firm is able to minimize risk (Cooper 2008; Cooper 1990). The activities within the stages are accomplished by a team of people from across the organization; no department is solely responsible for a particular stage (Cooper 2008).

After each stage an evaluation (gate decision) takes place: the goal of the gate is to determine if the new product should advance to the next development stage or be terminated. When a new product is in the initial stages of development, the gates are based on fairly abstract and incomplete information. However, as the new product progresses through the various development stages, the information used in the gates becomes much more sophisticated and defined (Hart et al. 2003).

### *Concept Testing*

The basic NPD process as described by Crawford and Di Benedetto (2008) is comprised of five phases: opportunity identification and selection, concept generation, concept/project evaluation, development, and launch. For the purposes of this study, the concept evaluation stage is the focus. During this stage, the firm evaluates the concepts generated in phase two. The concepts are evaluated based on marketing, technical, and financial criteria, and the best two to three concepts move on to the development phase (Crawford and Di Benedetto 2008). Several activities occur during the concept evaluation stage, but the focus here is concept testing. Concept testing is just one method used to incorporate consumer input in the NPD process; other methods are beta testing (Dolan and Matthews 1993), the lead user method (Urban and von Hippel 1988), consumer idealized design (Cinciannelli and Magdison 1993), and Quality Function Deployment (QFD) (Sullivan 1986). Concept testing was chosen for this study due to the fact that it is often utilized alongside early prototypes, and because it can be applied to industrial products (Kaulio 1998). According to Ulrich and Eppinger (2008), the principal benefit of concept testing is the feedback received from actual customers or users of the product in question.

Due to the exploratory and often qualitative nature of concept testing, it is essential to interview as many stakeholders as possible associated with the

proposed product (Patrick 1997). Those who will be involved in the purchase or use of the product or how it might be improved must be consulted during concept testing (Crawford & Di Benedetto 2008). The vast majority of concept testing occurs through personal contact, such as direct interviewing or telephone interviews (Crawford & Di Benedetto 2008). Even though concept testing can be done over the phone, face-to-face interviews are ideal because they give the interviewee an assurance of confidentiality, the option to ask questions if something is unclear, and the ability to see a physical sample of the product (Crawford & Di Benedetto 2008, Patrick 1997). The qualitative information gathered through open-ended discussions with interviewees may be the most valuable result of concept testing (Ulrich & Eppinger 2008), since the goal is to explore what people are doing and thinking, rather than taking a poll (Crawford & Di Benedetto 2008).

Prior to asking questions of the interviewee, it is important to communicate the concept. This can be done in a variety of ways, from a verbal description of the product to the presentation of a working prototype (Ulrich & Eppinger 2008). The order in which information is gathered during a concept testing interview is important. First, the interviewer should acquire background information, followed by information about the product concept itself. In order to get a feel for the interviewee's take on the product concept, the interviewer

might ask if the concept solves a problem; what changes could be made to the concept; what the concept would be used for and why; or what products or processes the concept would replace (Crawford & Di Benedetto 2008).

Once the concept testing interviews are complete, the results must be used with caution. The only real information acquired is an indication of likely product acceptance (Cooper 2001). If the product concept is innovative, new, or unfamiliar to the interviewee, the results may actually understate the product's acceptance (Cooper 2001). This is due to the fact that unfamiliar concepts tend to draw a negative response initially, but the response is often changed with time and exposure (Cooper 2001, Crawford & Di Benedetto 2008). The information gleaned from concept testing should be used to decide whether or not to proceed to the next step of the NPD process.

Although extensive research has demonstrated the importance of concept testing (Crawford and Di Benedetto 2008; Cooper et al. 2005; Cicianntelli and Magdison 1993), research has also doubted its usefulness (Tauber 1975). Tauber (1975) argues that the attitudes and intentions gained from concept testing do not relate to a person's adoption behavior later on, and that concept

testing fails because it does not measure the two most important factors for new product success: adoption and frequency of purchase.

### *New Product Success and Failure*

Since the 1960's, many studies have acknowledged the high frequency of industrial new product failure (Booz et al. 1968; Cooper 1979). As a result, tremendous work has been done in an attempt to understand why some products are successful while others fail (Cooper and Kleinschmidt 2000; Cooper 1988; Cooper 1979). One such example is a study by Cooper (1979) aimed to identify the major factors that contribute to a new industrial product's success or failure. This type of study is of great importance to industrial firms because "many of the variables which might separate the 'winners' from the 'losers' are within the control of the firm" (Cooper 1979, p. 93). Cooper (1979) found that the most important dimension of new product success is product uniqueness and superiority. A unique and superior product tends to be very innovative and new to the market; meet the needs of the consumer better than existing products; help the consumer lower costs or do something formerly unachievable; integrate unique features for the consumer; and be of higher quality (more durable, lasts longer, more reliable, stronger) than the competitors' products (Cooper 1979). In addition to product uniqueness and superiority, market knowledge and marketing proficiency is also of great

importance to new product success (Cooper 1990; Cooper 1979). Companies with a solid understanding of customers' needs and wants, market potential, buyer behavior, competition, and price sensitivity tended to have success with their new products (Cooper 1979). Other than being familiar with the keys to new product success, one must also be familiar with its barriers. Cooper (1979) identified three common barriers to new product success: making an expensive product relative to competing products with no economic benefit for the customer; being in a market where many new products are introduced; and being in a market where customers are already satisfied and the competition is fierce. According to Crawford and Di Benedetto (2008), "the biggest cause of new product failure is that the intended buyer did not see a need for the item – no purpose, no value, not worth the price" (p. 191).

Within the forest products industry, four key factors for successful new product development have been identified (Bull and Ferguson 2006; Crespell et al. 2006; Stendahl et al. 2007). Primarily, the product must have superior customer value compared to competing products. Because this value is in the eye of the customer, market research focused on discovering the customers' needs, wants, and desires is of utmost importance. Secondly, the organization must have a structured NPD process that is backed by the entire company. Without cooperation and endorsement from the entire organization,

successful NPD is greatly hindered. Thirdly, the company's culture must have a market orientation. Without a market orientation, organizations will not be attuned to the needs and wants of the customer, making successful NPD difficult. Lastly, senior management must support the NPD process from concept generation to launch.

#### *Role of Design Professionals in NPD*

During the concept evaluation stage of NPD, the various new product concepts are investigated to see which one(s) should advance to the development stage. Concept testing is one tool used to glean opinions, insights, and suggestions from potential customers/users of a new product. It is important to interview as many stakeholders as possible, including those who will potentially decide to buy the product or know how it might be improved (Crawford and Di Benedetto 2008; Patrick 1997). Products in the forest products industry have a wide variety of stakeholders, such as producers, wholesalers, distributors, builders, contractors, architects, engineers, and end users. This research focuses on gaining insights from design professionals (architects, engineers, builders, etc.) in order to better understand how VTC wood could fit into their world. With regard to forest products, design professionals are an important group to understand. Their needs, wants, and preferences often determine the products they specify,

which in turn determine the products used in buildings. According to Schoormans et al. (1995), it is important to include “expert customers” in concept testing. Expert customers are those who have experience with a particular product or product category, which leads to greater understanding of new products during concept testing (Schoormans et al. 1995). In this research, design professionals are considered expert customers due to their frequent exposure to wood products.

## METHODS AND DATA ANALYSIS

Data for this study were collected by personal interviews, which are a common tool used in qualitative research. In personal interviews, data are collected via a face-to-face or telephone conversation between the interviewer and the interviewee. In this study the interviewer asked questions of the interviewee(s), which were audio recorded. The product concept was communicated with both a verbal description and a working prototype. The recorded responses were then transcribed word for word in order to ensure accuracy.

### **Methodology**

### *Personal interviews*

There are several advantages to personal interviews compared to other methods of data collection. First, the direct nature of personal interviews enables the researcher to avoid low response rates synonymous with other research methods (Barriball and While 1994, Goyder 1985). Second, the researcher has the ability to explore the interviewee's attitudes, beliefs, and motives in more depth compared to other research methods (Barriball and While 1994). Third, researchers may acquire additional information by asking follow-up questions guided by the interview or by interviewees providing additional information in response to questions the researcher did not think to ask. The primary disadvantages are cost and time.

## **Study design**

### *Interview protocol development*

A semi-structured interview, rather than a structured interview, was chosen for this study due to the exploratory nature of the questions. This type of interview was chosen because of the interviewer's ability to ask additional questions spurred by the interviewee's responses; a structured interview only allows the interviewer to ask questions found in the interview protocol.

Prior to beginning the personal interviews, a semi-structured interview protocol was developed. According to Flick (2002), a semi-structured interview protocol serves three main functions in an interview: ensures answers to the main topics are gathered from all interviewees, serves as a guide to keep both the interviewer and interviewee on topic, and keeps the interview moving forward if dialogue between the interviewer and interviewee lags or stops. The complete interview protocol used in this study can be found in Table 10.

**Table 10.** *Semi-structured interview protocol for design professionals*

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<b>Question</b>
1 What is your job title (architect, engineer, contractor, etc.)?
2 What are your biggest challenges with material selection today?
3 What do you look for/consider when specifying materials?
4 How often do you specify wood products compared to other building materials?
5 What are the benefits of wood-based materials vs. other building materials you're currently specifying?
6 In what applications do you find wood limiting because of strength properties? Other properties?
7 In which existing applications do you think VTC wood could be used?
8 Are there new applications you can identify, given the properties of VTC wood?
9 What do you see as advantages to the commercialization and/or use of VTC wood?
10 What do you see as barriers to the commercialization and/or use of VTC wood?
11 What do you consider a "deal breaker" concerning your decision to specify wood?

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### *Pre-testing*

Pre-testing of the interview protocol consisted of open-ended, casual interviews with five architects (two were from one firm, three from another). Those interviewed were chosen by convenience sampling, which may not produce the best results but saves on time, money, and effort (Patton 1990). The interviews provided a means to generate ideas, questions, thoughts, and reactions from key individuals concerning the specification and use of VTC wood. The information gathered during pre-testing was utilized to fine-tune the semi-structured interview protocol.

### *Development of interview reference materials*

An information sheet was created to provide the interviewees with materials to reference during the interview. The information sheet contained facts about the mechanical properties of VTC wood and those of commonly used wood species. Several graphs were also created to visually compare the density and mechanical properties of VTC wood and substitute building materials. The complete set of interview reference materials can be found in Appendix A. In addition, physical samples of undensified hybrid poplar and hybrid poplar treated with the VTC process were shown to the interviewees.

## **Data Collection and Analysis**

### *Snowball sampling*

The interviewees in this study were identified based on recommendations by those interviewed during pre-testing and through the use of “snowballing.”

Snowballing is the process of identifying new interviewees based on the recommendations of previous interviewees, and is “based on the premise that members of a rare population know one another” (Lohr 1999, p.403). It’s possible to create a large sample by snowballing; however it is not a probability sample due to the breach of statistical assumptions that occur.

### *Sample selection*

Before any of the interviewees were identified, interviewee criteria were determined. In order to be considered for this study, interviewees had to be design professionals with some experience working with wood. Based on those criteria, the first five interviewees were selected from recommendations from those interviewed during pre-testing and based on knowledge from the authors. At the end of each interview, the interviewee was asked to identify additional potential interviewees. Another five interviewees were selected

based on this information. The remaining nine interviewees were selected based on their firms' rating as a top one hundred architecture/engineering firm in a publication called the Portland Business Journal 2007 Book of Lists. Those interviewees were chosen due to their high ranking relative to other firms in the Portland metropolitan area. Nineteen interviewees was deemed appropriate due to previous research which has shown that twenty interviews are sufficient to provide a comprehensive understanding of a topic (Griffin and Hauser 1993). The interviewees are shown in Table 11 and are listed by interviewee category (profession).

**Table 11.** *Design professional interviewees by profession*

<b>Interviewee Category/Profession</b>	<b>Frequency</b>
<i>Architect</i>	9
<i>Structural engineer</i>	5
<i>Green building consultant</i>	2
<i>Civil engineer</i>	1
<i>Contractor</i>	1
<i>Architect/structural engineer</i>	1
<b>Total</b>	<b>19</b>

#### *Data collection*

The interviews ranged from 10 minutes to one hour in length, and were digital audio-recorded. Audio recording enabled the researcher to accurately

preserve the interview data and to be more immersed in the conversation (Yin 1994). The audio recordings were then transcribed verbatim, and the resulting transcripts were used for data analysis. In total, the transcribed interviews were 130 double-spaced pages of text (Arial font, Size 12).

Each interviewee was placed in one of three “interviewee categories”: architect, engineer, or other. The “architect” category includes architects only; the “engineer” category includes five structural engineers and one civil engineer; and the “other” category includes two green building consultants and one architect/structural engineer.

### *Data analysis*

After the interviews were transcribed, an exhaustive list of answers was compiled for each of the twelve questions in the interview protocol. Once the list was completed, the frequency of each response was recorded every time an interviewee mentioned it. This process was completed for each of the eleven questions. The end result was a list of the eleven questions asked with all corresponding responses, and a frequency of each response. The list was broken down by interviewee category for each question. This method of

analysis was deemed appropriate due to the exploratory nature of the research as specified by the objectives.

## RESULTS

The results of the study are presented in the following section. To ensure anonymity, all interviewees are referred to by their profession (i.e. architect, engineer, contractor, etc.). All results are presented regardless of the frequency of each response. The exploratory nature of this study placed equal value on all responses, regardless of how frequently it was mentioned. Responses with a frequency of one are considered equally “significant” to those with a frequency of ten, due to the wide range of interviewee background and the potential for VTC wood to be successful in a niche market.

### **Challenges With Material Selection**

Each of the nineteen interviewees identified their biggest challenge with regard to material selection. All responses are listed in Table 12 below from the highest to lowest frequency.

**Table 12.** *Challenges with material selection.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

Response	Interviewee Category			
	Architect	Engineer	Other	Total
Availability	2	3	1	<b>6</b>
Finding products that meet desired environmental characteristics	2		2	<b>4</b>
Using unfamiliar products	2	2		<b>4</b>
Finding durable exterior products	1	1		2
Compatibility with the code	1			1
Finding local products	1			1
Staying within the budget	1			1

The three most commonly mentioned challenges with material selection were product availability, finding products that meet desired environmental characteristics, and using unfamiliar products. Other challenges brought up by interviewees were finding durable exterior products, compatibility with the building code, finding local products, and staying within the budget. A third of

the interviewees identified material availability as their biggest challenge with material selection.

I think one of the major issues is availability. There were lots of times when we were really interested—we'd do a product search on the web. We'd even have a sample in our office of a particular product that we wanted to use, and we'd get excited about it, and get the client excited about it, and then the time would come for us to finally figure out where it was going to come from, and what the actual cost was, but mainly, where is it going to come from? That was a major issue.

*Architect/structural engineer*

There are lots of new materials out there, but the question is, when it takes a year of design and documents, and then a year or more for construction, then is it going to be available at the time, and at the price that was anticipated when it was being selected for the project?

*Architect*

In addition to material availability, using unfamiliar products was also a challenge for architects and engineers alike.

My biggest challenge with materials is having to specify things that I don't know about or am not familiar with.

*Structural engineer*

### **Considerations in Material Specification**

Seventeen of the nineteen interviewees identified one or more factors they consider when specifying materials. The two green building consultants do

not directly specify materials, so they did not answer this question. All

responses are listed in Table 13 below from the highest to lowest frequency.

**Table 13.** *Considerations in material selection.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

Response	Interviewee Category			Total
	Architect	Engineer	Other	
Availability	1	2	2	<b>6</b>
Cost	2	3	1	<b>6</b>
Building type	3	1		<b>4</b>
Environmental certification	3	1		<b>4</b>
Product locality	3	1		<b>4</b>
Durability	2	1		3
Maintenance	3			3
Embodied energy	2			2
Fire rating	2			2
Lead time	1	1		2
Life cycle analysis	1	1		2
Product familiarity	1		1	2
Appearance	1			1
Combination of factors			1	1
Product warranties	1			1
Speed of construction		1		1
Thermal properties	1			1

The five most commonly reported considerations in material selection were availability, cost, building type, environmental certification, and product locality.

Both availability and environmental certification were among the most frequently mentioned responses in challenges of material selection as well as considerations of material selection. Cost was mentioned as an important consideration by six interviewees; staying within the budget is of great importance in any building project.

We worry about cost from day 1, because the owner almost always has a budget.

*Architect*

In addition, building type, product maintenance, and product familiarity were frequently mentioned responses.

*Building type:*

Material choices are driven by cost and what type of building it is.

*Structural engineer*

*Product maintenance:*

We have to consider that this is a fifty-year-old building, and what type of maintenance is on a recurring basis. In a typical maintenance department, they don't really have the money and the resources to deal with wood on the outside of the building.

*Architect*

*Product familiarity:*

It's both investing money from your budget and investing energy as a designer; it's really about prioritizing. As architects, we only have so much time and energy to devote to different parts of the process. Truth be told in our field now, especially once you get to be a project manager or project architect, you only spend ten

percent of your time on your design work, and ninety percent of your time goes to organizing the rest of the professionals and clients around your project. You spend a small part of your time actually doing the design work. Which means that when you have time to do it, you have to pick and choose.

*Architect/structural engineer*

Anytime you use a product that you don't know, it could be a liability. You need to be cautious. We're looking for products that are virtually bullet proof.

*Architect*

### **Frequency of Wood Products Specification**

Throughout all of the interviews, it became apparent that the frequency of wood products specification is directly linked to the building type. In many cases, the building codes pre-determine when wood can and cannot be used in different types of buildings. The majority of commercial and industrial projects cannot use wood for structural purposes, while residential construction uses wood framing almost exclusively. As a result of these rules, the responses varied depending on the interviewee's firm, and the types of projects they were involved with. Interviewees reported a wide range of wood use: from almost always to fifteen percent of the time. One architect commented that architecture goes in trends, and the current trend does not emphasize the use of wood as much as previous trends.

I think architecture goes in trends. Right now we're in a different trend, so wood isn't being used as much as in the past.

*Architect*

### Benefits of Wood-Based Materials

All but five of the interviewees voiced various benefits of wood and wood-based materials. The responses are listed in Table 14 below from the highest to lowest frequency.

**Table 14.** *Benefits of wood-based materials.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

Response	Interviewee Category			Total
	Architect	Engineer	Other	
Cost		4		<b>4</b>
Ease of use	2	2		<b>4</b>
Availability	1		1	2
People love it	1		1	2
Sustainable		1		1
Versatile	1			1

Cost and ease of use were the two most commonly mentioned benefits of wood-based materials. Several interviewees mentioned the affordability of wood compared to other common building materials such as steel and concrete.

Wood usually wins out [over steel and concrete], because it's less expensive. *Structural engineer*

The responses 'availability' and 'sustainability' go hand in hand. According to one interviewee, wood products are sustainable because of their local availability.

From the sustainability standpoint, living in our area and using wood framing makes a lot of sense. It can be harvested locally, helps the local economy, and you can harvest it in a sustainable way so that it can be there for generations to come.  
*Structural engineer*

Two additional interviewees commented on the availability of wood as beneficial.

It's [wood's] availability. We have an abundance of it here in the Northwest. *Architect*

A benefit in the Northwest is that wood's a local material.  
*Green building consultant*

A few interviewees mentioned a less "hard" benefit of wood products: the love of wood. In some cases, design professionals can specify more wood for a building if the owner has a preference for it, which is often done regardless of cost.

There are lots of opportunities, so we push it as hard as we can, because we like wood.

*Architect*

A lot of people like the look and the feel of wood, and don't want to cover it up with other materials.

*Green building consultant*

### Limitations of Wood

Each interviewee reported one or more limits of using wood in building construction. All of the responses are listed in Table 15 below from the highest to lowest frequency.

**Table 15.** *Limitations of wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

Response	Interviewee Category			Total
	Architect	Engineer	Other	
Long spans	2	3	2	<b>7</b>
Buildings over five stories		2	1	<b>3</b>
Fire rating	1	2		<b>3</b>
Walls with large openings	1	2		<b>3</b>
Dimensional stability	2			2
Exterior exposure	2			2
Expansion and contraction	1			1
Floor-to-floor height		1		1
Future building adaptability		1		1
Maintenance		1		1

The most commonly mentioned limit of wood was not being able to achieve long spans. Several interviewees voiced complaints concerning the depth of the beams necessary in order to span long distances.

A major disadvantage of wood is that you need depth in order to get span. If there were ways to minimize that, it would definitely have some advantages.

*Architect/structural engineer*

The issue with wood is that when you compare it to other materials, the depth of it gets so deep to get similar length and spans, that's limiting.

*Structural engineer*

We've had projects where we have actually had a wood building, and had to come and put steel beams in it, because the wood couldn't span.

*Structural engineer*

One interviewee stated that there are no limits to wood because once you choose it as a building material you are already aware of its limits, and you still chose to use it anyway.

If it's a given that we're using wood, we already know what the restrictions are. Some of the imperfections that come with wood are endearing, some not quite so endearing.

*Architect*

### Products to Incorporate VTC Wood

Interviewees were asked to identify both existing products that could benefit from the incorporation of VTC wood, as well as any new product ideas. The nineteen interviewees identified over twenty products that could potentially incorporate VTC wood, but no new products were suggested. Table 16 lists the interviewee responses from the highest to lowest frequency.

**Table 16.** *Products to incorporate VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

Response	Interviewee Category			Total
	Architect	Engineer	Other	
Glulam beams	6	3	1	<b>10</b>
Flooring	4	1	3	<b>8</b>
Cabinetry	2	2	2	<b>6</b>
LVL	2	2		<b>4</b>
Doors	1		2	<b>3</b>
Wall/ceiling panels	3			<b>3</b>
Boats	1	1		2
Concrete forms	1		1	2
Exterior siding	2			2
Plywood		2		2
SIPs panels	1	1		2
Window cladding	2			2

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Basket weave ceiling	1		1
Benches		1	1
Decking			1
Furniture		1	1
I-joists		1	1
Light fixtures	1		1
Retrofitting		1	1
Shear walls			1
Specialty pallets			1
Trellises		1	1
Underlayment			1

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Of all the products mentioned, glulam beams were suggested the most frequently. Several interviewees were intrigued at the prospect of being able to span wood beams longer without having to simultaneously increase their depth.

One thing it might be really useful are tension laminations in glulam beams. You could get equivalent values, if not greater ones, and because you could use less wood, you'd end up with shallower glulams, but similar or greater strength, which would really be advantageous.

*Architect/structural engineer*

With glulams, there are lots of opportunities for a higher tensile strength on the top and bottom laminations.

*Architect*

I can imagine a glulam; you could use less material and get the same strength.

*Architect*

There might be a way to sandwich this material around something else that isn't as dense in the core, with the VTC wood at the edges where it can do the most work.

*Architect*

Structural products weren't the only ones mentioned; flooring was mentioned as a viable possibility to several interviewees.

I'd think the density and durability would be a huge advantage for finish flooring and baseboards.

*Contractor*

I was thinking that it could be a veneer for a wood floor. I don't know exactly how hard it is, but it seems like you could use a thinner subfloor by using this. *Green building consultant*

There are so many different products out there that are trying to emulate wood, especially in the flooring industry, so finding a reason why this is better would be interesting.

*Architect*

An architect speculated that VTC wood flooring has the potential to capture some of the flooring market away from bamboo, due to its more local origin.

Because poplar is a rapidly renewable material, the ability to create flooring out of this would give bamboo a run for its money. We struggle with materials like bamboo and linoleum as qualifying for green because of the way they're produced. Linoleum from Europe, and bamboo from China—all the shipping associated with that, and both products are very heavy. With this being very lightweight, that's encouraging.

*Architect*

A few of the product ideas mentioned were based on the hope that VTC wood will eventually be able to be used in an outdoor application; to possibly be treated with something that would enable it to come in direct contact with water while remaining dimensionally stable. Outdoor products mentioned were boats, exterior siding, trellises, and decking.

It [VTC wood production process] takes more energy, but the alternative is, if you want to use actual wood for your decking, like local cedar—it's slow growing and expensive because we don't have a lot left. That's a local option, but if you go the other way with tropical hardwoods, then you're harvesting wood in Brazil. *Architect/structural engineer*

One interviewee pointed out that VTC wood could be used in export products because it is lightweight. Shipping lighter products would help reduce the amount of fuel used.

Anything that's going to be produced in Oregon, or domestically, and shipped--this could be a candidate for that because it is quite lightweight.

*Architect*

Additional products mentioned were cabinetry, doors, LVL, wall/ceiling panels, concrete forms, plywood, SIP panels, window cladding, furniture, I-joists, light fixtures, retrofitting, basket weave ceilings, shear walls, specialty pallets, benches, and underlayment.

### **Advantages to the Commercialization/Use of VTC Wood**

Every interviewee suggested at least one advantage to the commercialization and/or use of VTC wood. Table 17 lists all interviewee responses from the highest to lowest frequency.

**Table 17.** *Advantages to the commercialization/use of VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

<b>Response</b>	<b>Interviewee Category</b>			<b>Total</b>
	<b>Architect</b>	<b>Engineer</b>	<b>Other</b>	
Increased mechanical properties	5			<b>5</b>
Ability for greater spans	2	2		<b>4</b>
Appearance/color darkening	2	1	1	<b>6</b>
Create a sustainable product	1	1		2
Rapidly renewable resource		2		2

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Carbon sequestration in plantations		1	1
Create a high-value product from a low-value wood		1	1
Lightweight	1		1
Quick production process		1	1
Ability for greater spacing	1		1

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Of the ten suggested advantages to VTC commercialization, increased mechanical properties was the most common.

One of the advantages [of VTC wood] from a framing standpoint is the stability and the straightness of the pieces, and the increased structural value, which would thin out 2 x 6 walls back to 2 x 4 or spacing from 16 to 24 inches. *Architect*

From a structural aspect, VTC wood would be an awesome advantage, but whether it's affordable versus the wood and light gauge steel that you use for interior applications, I have no idea. *Architect*

An advantage of this product—it sounds to be denser, so it's going to be more stable, and be less prone to tension and compression, which is the primary failure factor of finishes on wood. *Architect*

We're really thirsty for is a product that has high performance at a reasonable cost. *Architect*

From a more aesthetic point of view, several interviewees considered the darkening in color that results from the VTC process as an advantage.

I don't think that the darkening is an issue at all; it could actually be used as an advantage. *Architect/structural engineer*

It [the darkening that occurs during the VTC process] makes it a richer wood. It makes it a better candidate for flooring.  
*Architect*

Another benefit is it gives poplar more dimension. This [undensified wood] is like vanilla ice cream, and this one [VTC wood] is like coffee mocha ice cream.  
*Architect*

I think the VTC wood has an interesting look. It's difficult to tell from such a small sample, but if the uniformity of appearance is consistent on a larger scale, I think that would very appealing to many designers.  
*Architect*

In addition to increased mechanical properties and improved appearance, interviewees reported two related advantages to VTC wood: making a high-quality product from a low-quality wood, which is also a rapidly renewable resource.

Poplar grows fast, and I think it would be fantastic if structural materials could be made from it. I'd be thrilled and eager to use it. What really intrigues me is (1) it's rapidly renewable, and (2) it's locally provided, and not trucked from thousands of miles away.  
*Architect*

You're taking a product that has very little value, and you're doubling the value. So, you may be reducing the volume, but you're increasing the value.

*Structural engineer*

### **Barriers to the Commercialization/Use of VTC Wood**

Each interviewee identified one or more potential barriers to the commercialization and/or use of VTC wood. Table 18 lists all interviewee responses from the highest to lowest frequency.

**Table 18.** *Barriers to the commercialization/use of VTC wood.* This table shows the frequency of each response by interviewee category. Bold numbers indicate the most frequently mentioned responses.

<b>Response</b>	<b>Interviewee Category</b>			<b>Total</b>
	<b>Architect</b>	<b>Engineer</b>	<b>Other</b>	
Cost	1	3	2	<b>6</b>
Energy use in production	3	1	2	<b>6</b>
Unfamiliarity	2	2	1	<b>5</b>
Appearance	3			3
Extensive testing needed for people to spec it	2		1	3
Code approvals		2		2
Potential color inconsistency	2			2
Brittleness		1		1
Lead time		1		1
Supply			1	1
Wood-water relations		1		1

Of the eleven barriers mentioned, cost, energy use during the VTC process, and unfamiliarity with VTC wood were the most common. One interviewee believed cost to be the only barrier to VTC wood being successfully commercialized, while another thought cost would only come into play if VTC wood were used in a structural application.

The only barrier is cost. *Structural engineer*

In the end analysis, if this were a framing product, so it's enclosed as not to see it, the bottom line comes down to cost.  
*Architect*

Six interviewees voiced concern about the energy consumed during the VTC process, and one wondered whether the cost of production would outweigh the benefit of increased strength values.

A disadvantage would be the manufacturing process; it sounds expensive and energy consuming. I think you have to look at the cost versus the benefit. Not only monetary, but the cost to the environment. Are we really saving that much material by doing this, or is the material savings being offset by all the energy consumption it takes to make the product?  
*Structural engineer*

The third most commonly mentioned barrier to commercialization was unfamiliarity, both among design professionals and within the entire building industry.

It will take time to get it in the market, from your best sales people to the architect's front door.

*Contractor*

We generally like to see it used for a while, before being guinea pigs, unless it rarely has a lot of problems. We have a ten-year liability. If it fails, we're out there too. We try to be really careful about that.

*Architect*

Some of the guys might be innovative, but in general, we're just following what we've used before. *Contractor*

Usually, though, the most practical, easy to get your hands on products are the best, versus ones you're unfamiliar with.

*Structural engineer*

The hard part is getting the whole industry to accept the product.

*Structural engineer*

As construction is a very conservative industry, there is a lot of reluctance to use new products, and so making any headway is hard. Sometimes it's done a relationship at a time.

*Architect*

It's [specifying unfamiliar products] more about reputation. We're certainly willing and have used new products that maybe haven't been used in the Northwest, or haven't been used in a way in which we're doing things now. I think a key aspect is, who represents it? Is it someone we know? Do we have a relationship with them? Can we trust them? Are they telling us the truth?

*Architect*

In order for design professionals to feel comfortable enough with VTC wood to specify it, extensive testing needs to be performed. Only after an impartial third party does rigorous testing will many be willing to specify it.

I think that you're going to have to show a lot of testing data to prove that it performs the way that you say it does. Probably not just laboratory testing, but you might build something in Corvallis, and let it sit for a while. That will be the only way that a lot of people will be convinced. With any new product, you take a lot of large risks. We [architects] are a risk-adverse profession.  
*Architect/structural engineer*

It would have to have a proven track record. If you're using a glulam, it would have to have extensive testing and approvals before we would actually be able to specify it in our drawings.  
*Structural engineer*

One of the barriers seems to be the testing for all of these applications. The test that backs up performance, or any of the ASTM testing for various building materials, usually cost a lot of money. *Architect*

### **Deal Breaker to Use VTC Wood**

Interviewees were asked to identify a "deal breaker" as to whether they would specify VTC wood if it were available in the marketplace. Although similar to barriers, deal breakers differ in that they often cannot be overcome. The deal breakers mentioned were cost, code approvals, energy used during production, and lead times. In addition to being deal breakers, these four factors were also mentioned as barriers to commercialization. The deal

breakers reported were very consistent: nineteen interviewees identified only four deal breakers.

### **Relationship Among Design Professionals**

Throughout the interviews, it became apparent that design professionals are greatly impacted by the relationship and experience they have with other design professionals. This relationship can either be helpful or a hindrance, but seemed consistent from one interviewee category to another (i.e. architects generally seemed to feel the same about other design professionals, as did structural engineers and contractors). In many cases the decision of what material to specify is made jointly by the architect, engineer, and contractor.

The contractor didn't want to do it [build a building in a different order than usual]. It took educating them—we had to call people back East who had already done it and get the contractor involved. If they're really invested in it, as an engineer, you have to go to that. A lot of people don't want to do that, because they can just go to the pilot that they've always used, and then on to the next job. You really want someone who believes in it.  
*Structural engineer*

The architect and engineer have it [the building products] already specified. The negotiated work we do—we'll make recommendations—but it is based on what we've had experience with.  
*Contractor*

A lot of the time it is dictated by what the architect has already come up with. They usually have some idea what the building looks like, and they usually have an idea of whether they're going to use concrete, steel, or wood. Usually a project will come to us. Every once in a while we give input and might say that it will save a lot of money if you use wood, instead of concrete, for example, but we have pretty limited involvement in that.

*Structural engineer*

Contractors have a lot of say in what type of materials we use.

*Structural engineer*

Then the contractor came and said we couldn't do that, because it was too expensive. So, the job got scaled back a lot.

*Structural engineer*

Builders are very conservative. We find that to be our biggest challenge with market transformation is the acceptance and open-mindedness of the builders. They would look at this and say, "Poplar? Yeah, right. What happened to it?"

*Architect*

## DISCUSSION

### **Challenges and Considerations of Material Selection**

Design professionals take a wide variety of considerations into account when specifying materials. At times, the specification process can be challenging and frustrating. Availability was the most frequently reported challenge and consideration with regard to material selection. There are two main reasons

availability is an important concern and consideration for design professionals. One reason has to do with the time it takes to complete a building, from the initial building plans to the end of construction. It is not uncommon for a building to take over two years from start to finish, which can cause problems for both architects and engineers. If a product is specified in the blueprints toward the beginning of a project, it may not be available two years later when it is time to begin construction. The second reason availability can be of concern has to do with the quantity of specified materials. The available quantity of a particular material can vary from month to month, and may have a long lead-time due to increased demand or some other factor. This can cause problems for design professionals; forcing them to substitute a different product or change the design of the building altogether.

The second most commonly mentioned consideration of material selection was cost. The entire design professional team of a given project must work together to ensure the finished building does not exceed the budget. As reported by a few architects, this seems to be more difficult for architects than for engineers and contractors. In addition to cost, building type was a frequently reported consideration in material selection. Several design professionals stated that the building type (residential, commercial, industrial, etc.) determines a lot of the materials that can and cannot be used. For

example, the building code does not permit wood framed buildings above five stories, while almost all residential construction in the Pacific Northwest is built with a wood frame. Building professionals are able to specify the products they want, but must stay within the rules of the building code.

### **Benefits and Limitations of Wood**

Geography is a major determinant of the benefits of wood mentioned by the interviewees. Wood is more affordable, available, and sustainable in the Pacific Northwest compared to other areas of the world. This fact directly impacted the interviewees' reported benefits of wood: cost, availability, sustainability, versatility, and people's general love for the material. If this study were done in another region of the United States, or in another country, the reported benefits would likely differ.

The limitations of wood reported most frequently were long spans, buildings over five stories, fire rating, dimensional stability, and exterior exposure. These five responses can all be considered natural limitations of wood - limitations that exist because of wood's natural properties. VTC wood's increased mechanical properties may enable some of these natural limitations to be minimized or overcome. Increased strength and stiffness could allow for

longer spans, wood buildings over five stories, and improved dimensional stability. If VTC wood could remain dimensionally stable while in direct contact with water, a few of wood's other natural limitations could be minimized. Undensified wood's shortcomings associated with exterior exposure and maintenance could be reduced through the integration of VTC wood.

### **Products to Incorporate VTC Wood**

The nineteen interviewees mentioned over twenty products that could benefit from the incorporation of VTC wood. Both structural and nonstructural products were mentioned. Structural products, such as glulams, LVL, plywood, and concrete forms were mentioned with the highest frequency.

Glulam beams could have been mentioned most frequently due to the fact that the most commonly mentioned limitation of wood was long spans. Several interviewees seemed excited at the prospect of being able to span longer than wood is currently able, while increasing strength and minimizing depth.

Nonstructural products mentioned were composite flooring, cabinetry, doors, wall/ceiling panels, window cladding, and furniture. Of the nonstructural products, flooring was mentioned most frequently. One interviewee commented that VTC wood could be very successful in the composite flooring market, since it is made from actual wood. Many products in the composite flooring market are not made from wood; they only resemble it. VTC wood

flooring could attract consumers due to its increased strength, hardness, appearance, domestic origin, and the fact that it truly is wood. In addition, VTC wood's ability to be stained/colored would give consumers a wide range of flooring color options.

Although only mentioned by one interviewee in direct response to the products question, retrofitting was brought up in several interviews. Many interviewees discussed how retrofitting is becoming more and more popular, especially in the Pacific Northwest. One interviewee suggested that VTC wood could be used in retrofit projects to increase the strength of old timbers. For example, a few veneers of VTC wood could be adhered to an existing timber in lieu of having to replace the entire timber. In many retrofit projects, the main problem is that the strength of the timbers has deteriorated over time. VTC wood could contribute to the execution of more efficient retrofit projects.

### **Advantages to the Commercialization/Use of VTC Wood**

The two most commonly mentioned advantages to the commercialization of VTC wood were increased mechanical properties and the ability for greater spans. The increased mechanical properties, which are a direct result of the VTC process, are the most obvious advantage. Turning a structurally

unsuitable wood species, such as poplar, into a product three to four times stronger than Douglas-fir is extremely advantageous. Since long spans were emphasized as both a limitation of wood and a potential new product, it is no surprise that they were also frequently mentioned as an advantage. If VTC wood could facilitate longer spans than are currently possible, wood beams may be able to capture some of the steel market. Longer spans would open up more opportunities for wood to be used in both residential and commercial buildings.

Several of the other advantages mentioned were related to the current emphasis on green: creating a sustainable product, using a rapidly renewable resource, manufacturing a high-value product from a low-value wood, and sequestering carbon in poplar plantations. In an application like flooring, these 'green' advantages could make VTC wood competitive against a product such as bamboo.

### **Barriers to the Commercialization/Use of VTC Wood**

Interviewees mentioned ten potential barriers to the commercialization and/or use of VTC wood. The two most frequently mentioned barriers were cost and the amount of energy used during the VTC process. Cost and energy

consumption were not completely independent concerns; several interviewees wondered whether the energy costs needed to make VTC wood could consequentially make it unaffordable. Others were concerned that the energy used during the production process could produce large amounts of pollution or off gassing.

Another commonly mentioned barrier to commercialization was unfamiliarity with VTC wood. Uncertainty was likely a concern due to the fact that architects and engineers are held legally responsible for the products they specify up to ten years after the building is complete. As a result of this long window of accountability, some design professionals are weary to specify products they are not familiar with, and tend to only specify products that have gone through rigorous third party testing. Past research with design professionals found similar results; design professionals do not feel comfortable specifying products that have not been tested extensively (Knowles et al. 2010).

Additional barriers to commercialization mentioned were unfamiliarity with VTC wood, appearance, code approvals, brittleness, supply, potential color inconsistency, wood-water relations, and the extensive testing required for design professionals to feel comfortable with specifying it.

## CONCLUSIONS

Concept testing with design professionals revealed information about VTC wood's potential uses, advantages, and barriers to commercialization.

Overall, interviewees thought the properties of VTC wood are best suited for use in glulam beams, flooring, cabinetry, and LVL. The most commonly mentioned advantages to commercialization included increased mechanical properties, the ability for greater spans, and the color darkening that occurs during production; barriers included cost, energy use during production, and unfamiliarity. Overall, interviewees seemed to think VTC wood could be successfully commercialized if it is cost-competitive, energy-efficient, and extensively tested on a large scale.

Before VTC wood's ideal location in the market can be determined, cost of production must be known. If VTC wood is going to cost significantly more than high-grade veneer, for example, it may not be able to compete. If this is the case, VTC wood may be better suited to a specialty product in a niche market. Many design professionals' hesitance to try new products will be a significant factor in the success or failure of VTC wood.

In the future, it would be beneficial to conduct additional interviews where the interviewer was equipped with cost information for VTC wood. Samples produced from a continuous process, rather than a batch process, would present a more accurate representation of the final product's appearance and properties. Larger samples would be especially beneficial for design professionals, who in general are a very visual group.

#### LIMITATIONS

The three major limitations of this study were the interview locations, the interviewees themselves, and the interviewees' lack of understanding of the VTC process. The interviews were all located in western Oregon, which may have minimized the diversity of responses. However, this limitation may have been minimized because the majority of interviewees do work all over the U.S. The interviewees themselves could also be considered a limitation because of the way they were identified. Snowball sampling was used to identify most of the interviewees, but oftentimes the individuals solicited by the interviewer were unresponsive and an interview did not occur. As a result, interviewees with a particular personality or greater interest in VTC wood may have been the ones to consent to an interview. The third limitation was the interviewee's lack of understanding of the VTC process. The VTC process was explained to each interviewee prior to beginning the interview, and interviewees were given

the opportunity to ask questions if necessary. However, some interviewees may not have completely understood the VTC process and answered the interview questions without understanding VTC wood in its totality.

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## CHAPTER 5 – GENERAL CONCLUSIONS

The purpose of this thesis was to use concept testing to gain insight into the commercialization potential of VTC wood. Objectives of this study were to identify potential commercial applications for VTC wood, identify future markets for VTC wood that demonstrate potential for successful commercialization, and understand potential limitations of VTC commercialization. To meet these objectives, interviews were conducted with individuals in the forest products industry and with design professionals.

The first stage of interviews was conducted with individuals in the forest products industry. On the whole, interviewees thought the most viable uses for VTC wood were LVL, plywood, concrete forms, transportation components, and flooring. The most frequently mentioned advantages to commercialization included increased mechanical properties and the utilization of a low-value wood species; barriers to commercialization were cost and the forest products industry's resistance to change. Overall, interviewees thought VTC wood would be successful as long as it was not markedly more expensive than similar products.

The second stage of interviews was conducted with design professionals. In general, interviewees thought the properties of VTC wood are best suited for use in glulam beams, flooring, cabinetry, and LVL. The most commonly mentioned advantages to commercialization included increased mechanical properties, the ability to achieve greater spans, and the color darkening that occurs during production; barriers to commercialization included cost, energy use during production, and unfamiliarity. Overall, interviewees seemed to think VTC wood could be successfully commercialized if it is cost-competitive, energy-efficient, and tested extensively on a large scale.

The two groups of interviewees, while sharing some responses, differed most noticeably in a fundamental way. As a whole, the forest products interviewees were very preoccupied by the cost factor of VTC wood. Due to this preoccupation, the group often failed to think “outside the box.” Design professionals, on the other hand, placed equal weight on cost, energy use, and product testing. They were a more imaginative group, and tended to think about VTC wood’s potential without focusing solely on cost. Their creative thinking resulted in a much greater number of product suggestions that could benefit from the integration of VTC wood.

As a whole, the interviewees believed that VTC wood has the most potential being successfully commercialized as a component of LVL, flooring, and/or glulam beams. These three products were likely mentioned with the highest frequency because radical changes in production would not need to occur in order to integrate VTC wood. One (or more) of these three products would be a logical starting point for VTC wood to enter the market. LVL and glulam beams have the potential to gain market share from steel, which could be used as a selling point. Flooring, on the other hand, cannot be used structurally, but may garner higher profits than LVL and glulam beams. Unique product ideas that may warrant additional investigation in the future are components for car/truck/train/boat interiors, commercial truck/trailer beds, retrofitting, SIP panels, benches, specialty pallets/crating, furniture, and export products. While interesting, these types of products may not be worth exploring until VTC wood is proven in more conventional products, such as LVL or glulam beams. However, they should not be ignored due to their potential for higher financial returns.

Both groups of interviewees mentioned several potential barriers to the commercialization of VTC wood. However, the barriers mentioned with the highest frequency by both groups were cost (both cost in general and the cost focus of the forest products industry), the forest products industry's resistance

to change, energy used in production, raw material supply, and unfamiliarity. As these barriers were frequently brought up by individuals in both groups, special attention should be paid to their potential accuracy.

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APPENDIX

## Appendix A. Interview Reference Materials

